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Electromagnetic Pump Insulation Postirradiation Test Report

by W. A. Bezella, T. S. Huntsman, J. C. Cassulo, R. E. Holtz, and D. H. Thompson

Argonne National Laboratory, Argonne, Illinois 60439
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ELECTROMAGNETIC PUMP INSULATION POSTIRRADIATION TEST REPORT

by

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POSTIRRADIATION TEST REPORT

by

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ABSTRACT

This report presents the results of the postirradiation test phase of a program dedicated to evaluating the effects of irradiation on the electrical insulation characteristics of samples of insulation proposed for a large annular linear induction pump (ALIP). This electromagnetic (EM) pump is an important component of the Advanced Liquid Metal Reactor (ALMR). As part of the ALMR design verification testing activities, these postirradiation tests are the final phase of the program and focus on the referencing of the insulation bar sample properties after their irradiation in the Experimental Breeder Reactor-II (EBR-II). This report includes a brief description of the test program, the pre and postirradiation test procedures and examinations, and a documentation of the postirradiation test results. This postirradiation report also provides a description of the irradiation test phase and accompanying temperature test. In a previous report, the test results for the preirradiation tests and examinations were documented.

I. INTRODUCTION

As part of a comprehensive testing program to assess the effects of irradiation on insulation materials proposed for use in the large electromagnetic (EM) pump for the Advanced Liquid Metal Reactor (ALMR), a series of preirradiation tests and examinations were conducted. This report summarizes the results obtained for the final phase of this evaluation test program and includes a description of the centerpiece of the program, which is the irradiation of 39 insulation bar samples in EBR-II. In support of the irradiation activity, an examination and testing effort was conducted to reference and characterize the insulation samples prior to subjecting them to the effects of neutron irradiation. This report documents the test procedures and results obtained for this postirradiation phase of the EM insulation irradiation program which includes a description of the temperature test which subjected some insulation bar samples to conditions identical to those experienced during irradiation but without the radiation component. The preirradiation results along with a detailed catalog of the insulation bar samples was provided in a previous report.[1]

The EM insulation irradiation test program consisted of essentially three distinct phases: (1) a preirradiation test and examination phase, (2) an irradiation in EBR-II phase, and (3) a postirradiation test and examination phase. The pre and postirradiation phases essentially determined the physical characteristics and electrical performance of the insulation in order to determine the effects of irradiation on the electrical insulation behavior. The major feature of the test program was the irradiation phase in which the 39 bar samples contained in three canisters are irradiated for a scheduled 90 full power days in the J2 thimble of EBR-II. The test material envelope consisted of five types of bar samples using four insulation materials, three binder materials and two copper materials. The test temperature specified for the in-reactor test was approximately 850°F. In the EBR-II J2 test location (i.e., in radial shield outside of the core), a neutron fluence in the range of 1.7×10^{16} to 3×10^{17} n/cm^2 for the samples with a maximum fluence not to exceed 2×10^{18} n/cm^2 is expected. Further details of the irradiation program can be found in Refs. 2 and 3.

The postirradiation test and examination program was essentially identical to the preirradiation tests and examinations and is presented in Ref. 2. These tests consisted of a series of referencing checks and examinations of the several combinations of insulation materials and binders used in the irradiation phase. In addition, selected insulation bar samples were subjected to an accelerated aging test under high temperature and high voltage to assess the leakage current insulation capability of the material. The electrical performance of each bar sample was determined with Megger and Hipot electrical measurements. This preirradiation test program also served as a screening program in which various insulation material combinations were age tested. The results of this age testing program were used to select the most promising insulation materials for subsequent irradiation testing. Additional details on the preirradiation tests and examinations can be found in Ref. 3.

This report on the postirradiation tests on EM pump insulation materials is structured as follows. After a brief description of the EM insulation irradiation program provided in Sect. II, the postirradiation tests and examinations that were performed are presented in Sect. III. A description of the irradiation phase of the program that was conducted in EBR-II is presented in Sect. IV. The description of the postirradiation characterization data that were obtained is presented in Sect. V. The description and test results for the temperature test, which was conducted at conditions similar to those of the irradiation test but without the radiation, are provided in Sect. VI. Finally, in Sect. VII, a summary of the postirradiation results is provided.

II. EM PUMP INSULATION TEST PROGRAM

The objective of this program was to assess and confirm the adequacy of candidate insulation materials to perform the electrical insulating function in the EM pump at conditions expected in the ALMR environment. The work involved the irradiation of selected EM pump insulation (bar) samples in a representative neutron flux for a sufficient period of time and then to determine the resulting insulating performance. Exposure of selected insulation materials to a radiation field at elevated temperatures will provide some of the performance data necessary to insure that the insulation meets the physical and electrical requirements of the EM pump being designed for the ALMR.

The testing consisted of essentially three phases: a pretesting phase, an irradiation phase, and a posttesting phase. The pre and posttesting phases were designed to establish the effects of radiation on the physical and electrical properties of the insulating materials.

In an attempt to isolate the effects of irradiation, there were essentially four groups of samples that were subjected to various combinations of pretesting, irradiation exposure, and posttesting. The four groups of samples were to be tested in the following combinations:

- Aged, Irradiated/Temperature Tested and Aged
- Aged, Temperature Tested and Aged
- Irradiated/Temperature Tested
- Temperature Tested

The aged tests subjected the samples to an applied voltage in an air atmosphere for a specified time (i.e., up to a maximum of 500 h) at a temperature of 1346°F (730°C). These accelerated aging tests were performed on some samples before and after irradiation. Some samples, to aid in the determination of the effects of irradiation, were not irradiated but were subjected to the same duration (~90 days) and temperature (~1140°F, 616°C) in a nitrogen atmosphere as those samples being irradiated (Temperature Test).

A brief description of these three program phases is provided in the next three subsections. More details about the EM pump insulation materials irradiation test program can be found in Refs. 2 and 3.

A. <u>Preirradiation Test Phase</u>

The purpose of the pretesting was to characterize the insulation material both visually and electrically. These examinations and tests served as the reference baseline from which the subsequent irradiation induced changes were determined in the posttesting phase of the program. In addition, the preirradiation test phase served as a screening evaluation process for selecting the most promising insulation materials to be irradiated.

The preirradiation testing consisted of the physical and electrical tests needed to benchmark the insulation samples prior to the irradiation phase of the program. These tests were essentially identical to those conducted in the postirradiation test phase and include visual examinations, photographs, physical measurements, voltage/temperature aging tests, and electrical tests. The examinations and physical evaluations included determining the weights and dimensions of each bar sample. The crystalline structure analysis specified in Ref. 2 was not performed.

The electrical tests that were performed included both a direct current resistance test as well as an alternating current leakage current test. Other special electrical tests (i.e., partial discharge, loss tangent, and breakdown voltage) as originally specified in Ref. 2 were not performed due to their projected expense.

The accelerated aging tests were short duration, high temperature and voltage tests performed in an oven. The test setup and conditions were similar to those used in the past for the ALMR EM pump insulation materials life testing program at ANL-East. The bar samples were placed in an oven in an air atmosphere. A high voltage (e.g., either 600 V AC or 1500 V AC depending on the bar sample type) was applied to the insulation and the leakage to ground current monitored. The temperature for these accelerated aging tests was 1346°F (730°C), with the test duration being 500 h (approximately three weeks) or 350 h (approximately two weeks) depending on the sample type.

As part of the preirradiation test phase, several shorter duration (~1 day) aging tests were conducted. These tests were essentially conducted to check out the performance of new combinations of insulating materials. Based on the results, the most promising insulation materials were selected for irradiation.

The procedures and preirradiation test specifics are presented in more detail in Sect. III and in Ref. 2. The preirradiation test results are reported in Ref. 1

B. Irradiation Testing

The irradiation program was conducted in the J2 thimble of EBR-II. This irradiation facility, called the Nuclear Instrument Test Facility (NITF), is located outside the core in the shield region and is an air-cooled thimble. The 39 selected bar samples were contained in three stainless-steel canisters (13 samples in each canister); this J2 thimble test was designated the NI-10 test. The canisters were filled with nitrogen gas and sealed initially at one 1 atm pressure. The temperature histories of the three canisters were recorded by two thermocouples attached to each canister. The neutron flux at the three canister locations was determined by a neutronic calculation. The experimental determination of the neutron flux was not possible as sufficient funding was not available. The duration of the irradiation phase of the program was specified as 90 days, however, this requirement was adjustable depending on the EBR-II irradiation cycle schedule. Based on the latest EBR-II fuel cycle projections, an irradiation duration of ~92.5 days was obtained for the EM insulation bar samples in the NI-10 EBR-II irradiation test.

In conjunction with the irradiation of the bar samples, a temperature test was conducted in an oven at ANL-East. Using an identical fourth canister, 13 bar samples were inserted and sealed in a nitrogen atmosphere. This canister was placed in an oven at the highest irradiation canister temperature observed in the EBR-II irradiation (1140°F, 616°C) and was operated at this temperature for the same duration as the irradiation samples (estimated to have been ~92.5 days). A comparison of the insulation electrical performance of these samples with that of the irradiated samples should help identify the influence of the irradiation on electrical insulation behavior.

Further details on the specifics of the irradiation aspects of the EM pump insulation irradiation program can be found in Ref. 3.

C. Postirradiation Testing

The postirradiation testing phase essentially was a repeat of the series of examinations and tests conducted during the preirradiation phase (see Sect. II.A). The major difference between the two phases, of course, being the fact that in this testing phase the samples are slightly radioactive. This factor has several implications on the resulting methods and test procedures that are employed in the posttesting phase. The activity level of the irradiated bar samples was measured and estimated analytically. In addition, three typical insulation bar samples were irradiated in a special test capsule in the Neutron Radiation (NRAD) test facility at ANL-West (see Ref. 1 for details). Based on an assessment of these results, the required decay time and adjusted test procedures were established. It was decided that these postirradiation examinations, accelerated age tests and electrical tests would be performed at ANL-West, which was better equipped to deal with radioactive materials than is ANL-East.

III. DESCRIPTION OF EXAMINATIONS AND TESTS

The postirradiation examination and test phase of the EM insulation irradiation test program as presented in detail in Ref. 2 is summarized briefly below. Because of high sample activity level and monetary constraints, not all of the electrical tests as specified in Ref. 2 were performed. In addition, the original sample matrix was expanded to incorporate other combinations of insulating/binder materials. These tests were essentially identical to the preirradiation tests and examinations, the results of which are reported in Ref. 1.

Summarized briefly below are the general descriptions and compositions of the various insulation bar samples studied in this EM pump insulation irradiation program. The various preirradiation examinations and tests are also described. The actual postirradiation data are presented and discussed in Sects. V and VI.

A. <u>General Descriptions</u>

The bar samples evaluated in this program consisted of a copper bar wrapped with an insulation material and held together with a binder material. Five types of bar samples, approximately 10 in. long, using four insulation materials, three binder materials tested and two copper materials comprised the materials test matrix. The two copper materials tested were GlidCop AL-15 (C15715) and Electrolytic Tough Pitch (ETP) Copper (C11000). The four insulation materials are splitting mica, muscovite (white mica), phlogopite (amber mica), and Nextel™ (a ceramic tape from 3M Corp.). Three types of potting compounds were used as a binder to hold the insulation together on the copper bar; one binder developed by the Corning Co. consisted primarily of silicon and aluminum, the second binder was SECON-5 (its main constituents are oxides of silicon, lead and aluminum), and the third binder was boron nitride, comprised primarily of boron nitride, aluminum oxide.

The insulation bar samples were fabricated by either the General Electric (GE) Co. or the Toshiba Corp. with different materials and slightly different dimensions. Figure 1 illustrates the splitting mica bar sample or Toshiba design. A total of 19 insulation bar samples of this design were included in the program. These 19 samples were designated by a single digit (i.e., 1 to 19). As Fig. 1 indicates, these splitting insulation bar samples were 280 mm (~11 in.) long with several layers of mica wrapping. The cross-sectional dimensions shown for the outside of the insulation are approximate with actual dimensions measured as part of the preirradiation (see Ref. 1) and postirradiation examinations (e.g., see Sects. V and VI). The silicon binder was used only on the ends of the top layer to anchor the alumina tape (i.e., splitting mica).

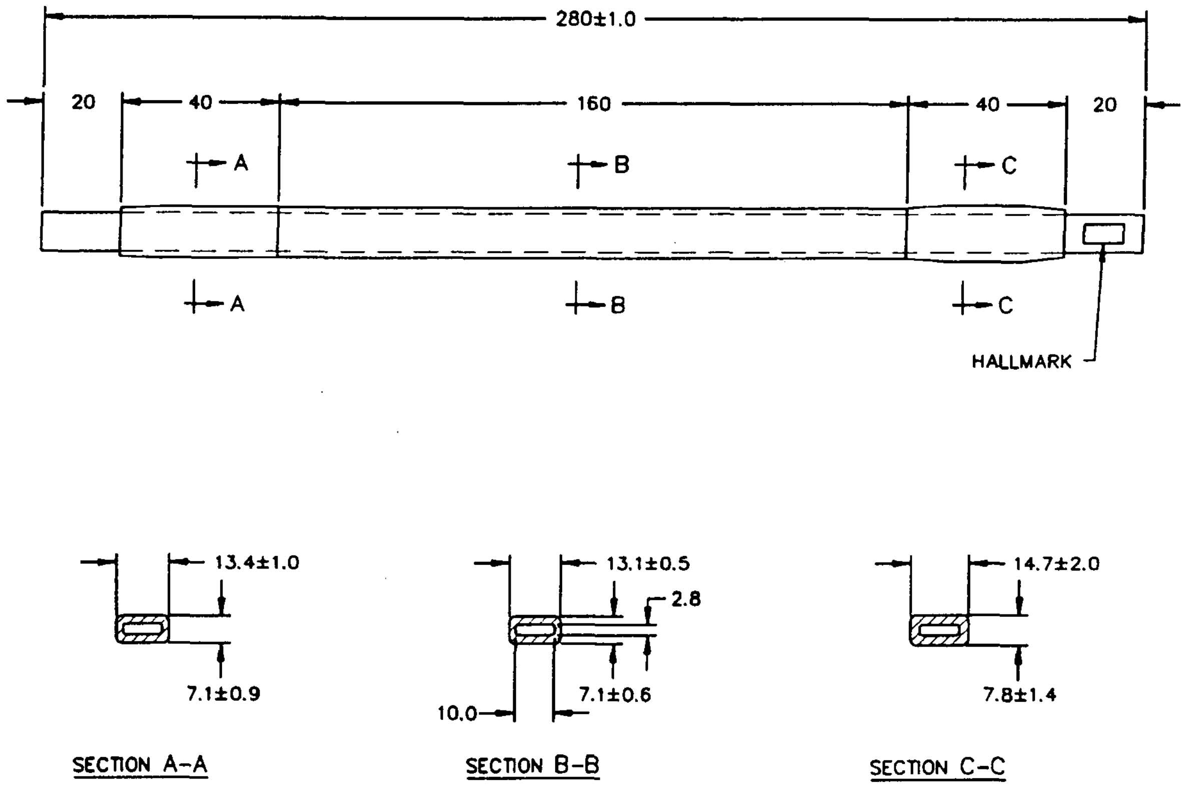
The General Electric insulation bar sample design is described in Fig. 2, this bar sample's overall length is 10¾ in. (254 mm) with the insulation length being about 10 in. (254 mm). As specified in the notes on Fig. 2, there were several insulation combinations fabricated to this GE bar sample design. The 21 amber mica/Secon-5 insulation bar samples were designated with numbers G1 through G20 and G43. The 22 white mica/Secon-5 insulation bar samples were designated with numbers G21 through G42. Several amber mica/boron nitride samples were also included in the program (numbers 1A, 2A, etc.) as well as Nextel/boron nitride insulation bar samples (numbers N10 through N19). In addition, several special combination insulation samples (i.e., different wraps of mica and ceramic tape and different binders) were added to the program. These samples had a sample bar designation identified with a "C" classification or a sample number in the 90 range. Again the cross-sectional dimensions shown in Fig. 2 are approximate with the actual dimensions for each GE bar tabulated for the preirradiation phase in Ref. 1 and for the postirradiation phase in Sects. V and VI.

The description of the various types of standard insulation bar sample materials (i.e., those samples in the original test matrix of Ref. 2) and approximate typical weights are tabulated in Table I of Ref. 1. Identified also in the Appendix of Ref. 1 are the associated weights (percents and approximate total weights) and compositions of the copper bars, insulation and binders. The weights are based on a typical insulation bar and represent average values for use in the irradiation evaluations (e.g., neutron activation calculations).

The description and numbering key of the various special insulation bar samples is shown in Table II of Ref. 1. As requested by GE, these ceramic tape insulation (i.e., Nextel tape) and a combination of ceramic tape and mica tape insulation using various binders were added to the test program. They were mainly subjected to an accelerated age test of varying duration. Based on their performance in these tests, several of these ceramic insulation/binder sample combinations were selected to replace some of the white mica insulation samples in the EBR-II irradiation test.

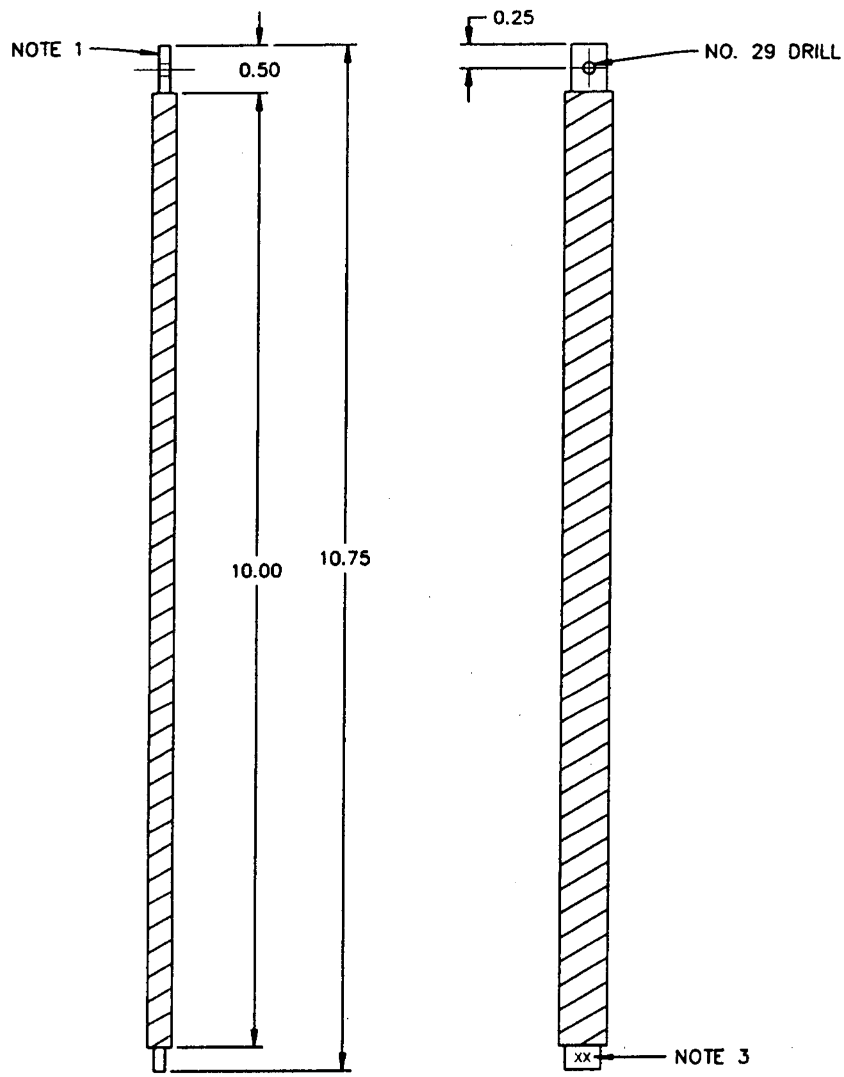
B. <u>Physical Examinations</u>

As part of the preirradiation phase of the program, each bar sample was visually examined and a photograph taken to provide a visual record of its overall condition. Most of the samples were subjected to weight and dimensional measurements. Prior to taking these measurements, the samples were kept in an oven at ~120°F (49°C) for several days in order to control the moisture level. To prevent the insulation tape from unraveling for some



Notes:
1. Dimensions are in millimeters (mm).
2. Cross sections are rotated 90°.
3. Bar is made with Aluminum Dispersion Strengthen Copper, Glidcop, AL-15 (C15715).
4. Alumina cloth backed amber splitting mica tape (0.3 mm thick, 25 mm wide) is 2/3 lapped one layer with a silicone binder on bar, underside of tape and on outside of layer. Alumina tape (0.2 mm thick, 25 mm wide) is 1/2 lapped one layer as top layer for protection. Silicone binder is used only on ends of top layer for protection. Silicone binder is used only on ends of top layer to fix alumina tape.
5. Bar sample numbers 1 through 19.

Fig. 1. Splitting Mica Bar Sample Description



Notes: 1. Bar is made with 0.115 in. x 0.376 in. flat copper wire C11000 Electrolytic Tough Pitch Copper, dimensions in in.

2. Insulation descriptions: 21 bar samples (Numbers G1 through G20 and G43) wrapped with amber mica/Secon 5, 21 bar samples (Numbers G21 through G42 wrapped with white mica/Secon 5, wrapped with amber mica/boron nitride (Numbers 1A and 2A), Nextel 440/boron nitride (Numbers N10 through N19) and special combinations B series and 91, 93 and 97.

3. The bar number is stamped on each bar at the location indicated.

Fig. 2. Mica and Ceramic Bar Sample Descriptions

samples, a thin ceramic thread was tied around the ends of some of the bars. In these examinations, the width and thickness of the bar sample including the insulation were recorded. The thickness dimensions were made at five places along the bar at approximately equally spaced places over its insulated length. These dimensions were obtained to the nearest 0.01 of an inch (0.254 mm). Figure 3 indicates the axial locations where the bar sample insulation thickness is measured. The weight of each bar that was weighed (some were not because they were still wet and required curing) was recorded to the nearest 0.01 of a gram.

The crystalline structure analysis as specified in the original test requirements document (see Ref. 2) was not carried out. This test was to consist of preparing a cross section of the insulation for two samples of each mica type (i.e., white, amber and splitting) and then examining and photographing the samples under magnification using the scanning electron microscope (SEM).

C. Electrical Testing

The preirradiation electrical testing of the insulation bar samples consisted of two tests; (1) a Megger test and (2) a Hipot test. These are standard electrical tests universally performed to determine the electrical resistance of materials. For both of these tests, the bar sample's insulation was wrapped with a thin sheet of aluminum foil to insure that good contact was achieved between the insulation and the electrode. In both of these tests a consistent procedure regarding the preparation of the sample, location of the electrodes and recording of the data was maintained for every sample. All samples were kept in an oven at ~120°F (49°) for several days prior to these tests to insure that the samples were dry and not subjected to differing levels of sample moisture.

Megger Test: The Megger test consisted of measuring the insulation electrical resistance by attaching the hot electrode to the bar and the ground electrode to the outside of the insulation. In this test, 1000 V DC was applied for about 1 min and the resistance recorded in gigaohms. This test was performed with the bar sample at room temperature.

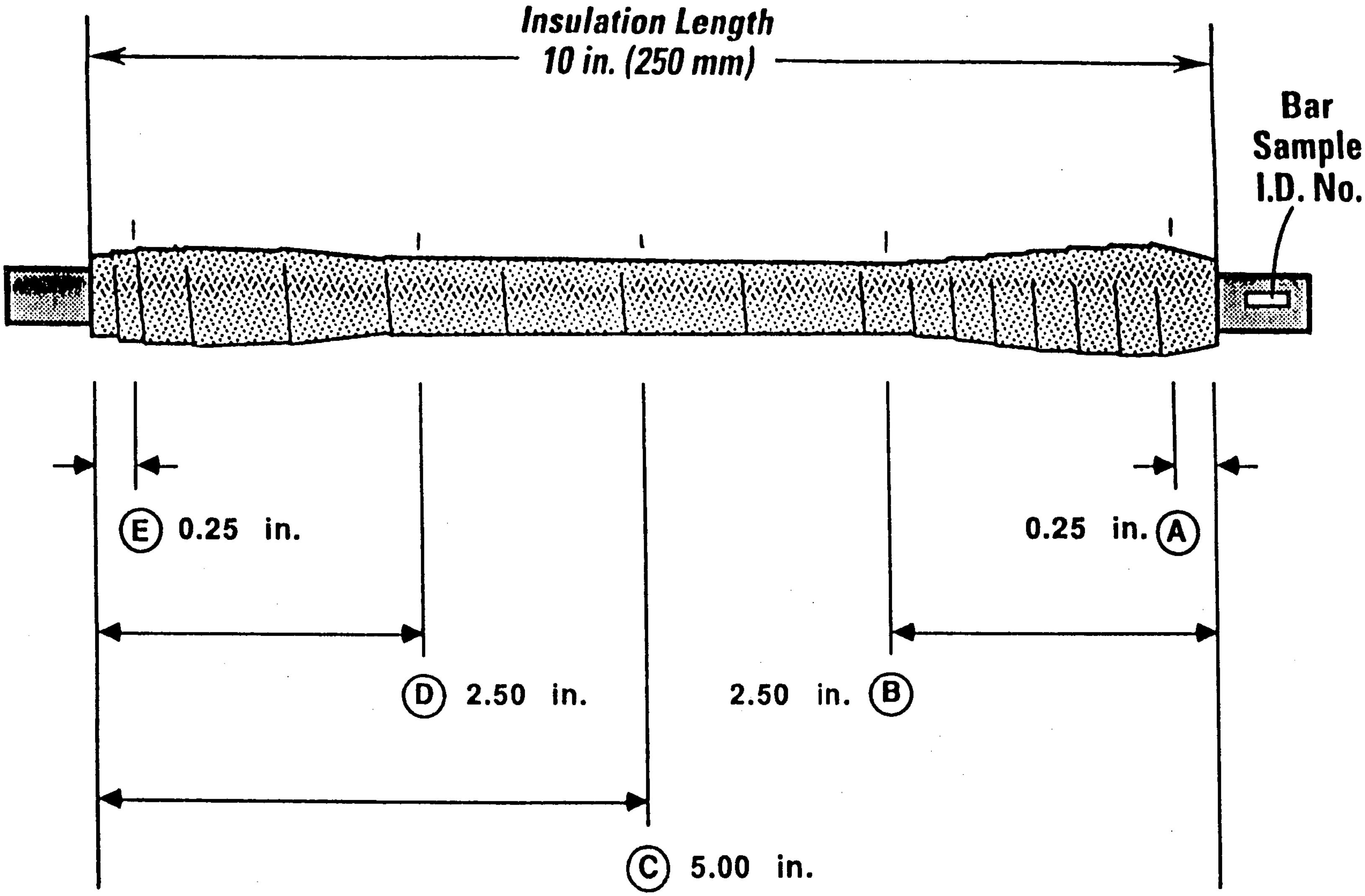


Fig. 3. Axial Locations Where Bar Sample Insulation Thickness is Measured

<u>Hipot Test</u>: The Hipot (high potential) test was performed at 3000 V AC, 60 Hz at room temperature. The meter electrodes were attached as in the Megger test; the voltage was applied for about 1 min. The leakage current was recorded for each sample in milliamps.

D. Accelerated Age Testing

All of the accelerated age tests on the insulation bar samples were conducted in the specially fabricated ovens which were designed at ANL-East. The accelerated age testing of the slightly radioactive bar samples irradiated in EBR-II was performed in an oven at ANL-West which was shipped from ANL-East. The test setup and procedures were almost identical to those used in the insulation life testing currently underway at ANL-East on the U.S. ALMR EM pump insulation life testing program.

Figure 4 presents an illustration of the typical oven that was used in the accelerated aging tests. The ovens have inside heater compartment dimensions of approximately 18 in. by 18 in. by 6½ in. (45.7 cm x 45.7 cm x 16.5 cm) and are constructed of fire brick with an outside sheath of Kaylo. The oven top consists of two layers of 1 in. (2.54 cm) thick Fiberfrax. Four small plate two heaters, 14 in. x 5½ in. x ⅝ in. (35.6 cm x 14.0 cm x 1.6 cm), supply the heat from a 208 V power supply. The outside dimensions of the oven are about 30 in. x 30 in. x 14 in. (76.2 cm x 76.2 cm x 35.6 cm). The heater electrical leads were brought out through the sides of the oven bricks through 6 in. (15.2 cm) ceramic sleeves. The electrical leads for the applied sample voltage were brought out through the oven top cover. Temperature control was provided with a thermocouple connected to a temperature controller/recorder. A voltage transformer provided the applied voltage to the sample with sample leakage current measured with an ammeter. A 62 milliamp fuse in the leakage current circuit provided sample insulation failure indication and interrupted the applied sample voltage.

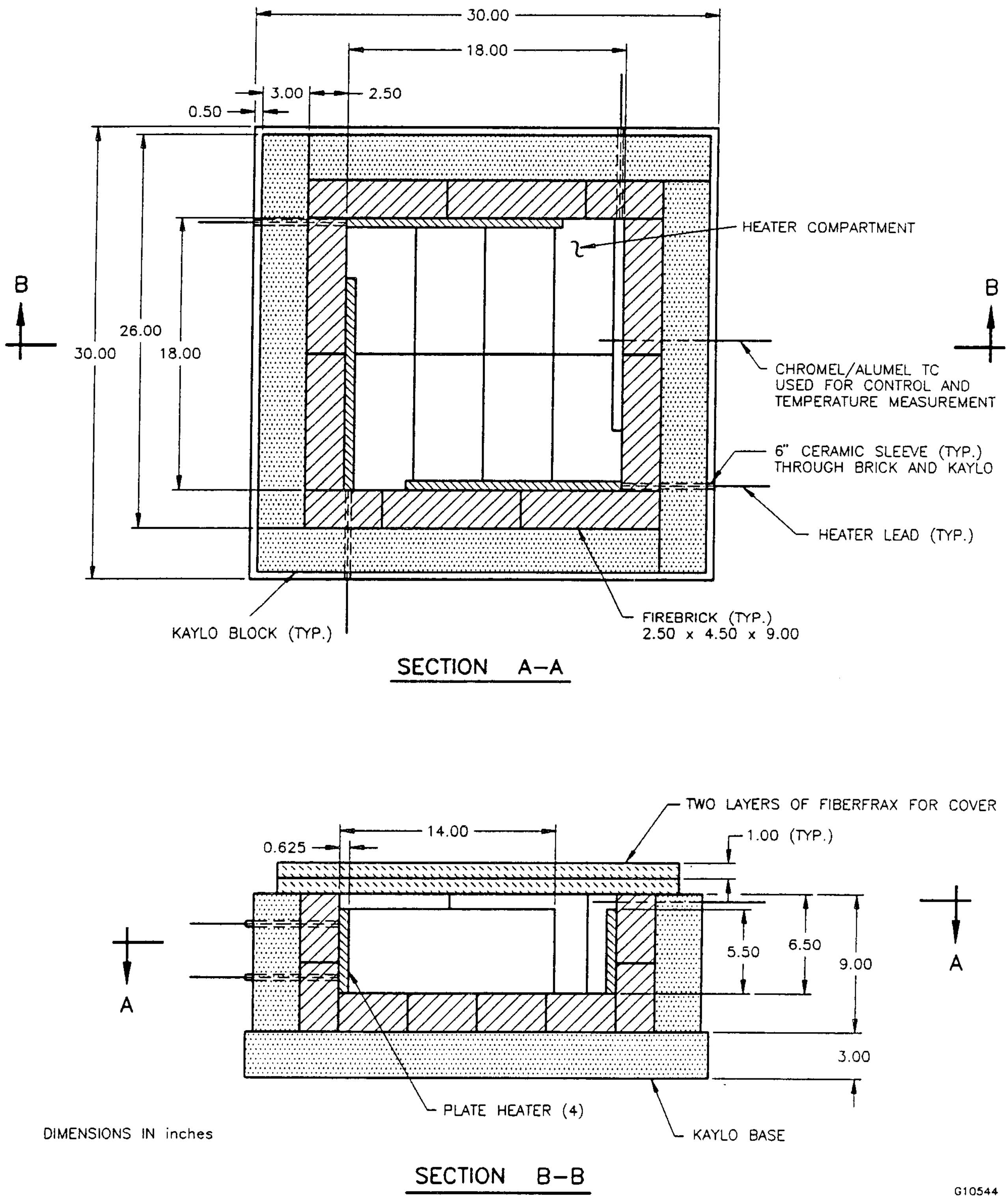


Fig. 4. Oven Used in Accelerated Aging Tests

As specified in Ref. 2, the original preirradiation test matrix called for short-term aging tests for 500 h with applied voltages of 600 V AC for the splitting mica samples and 1500 V AC for the white and amber mica samples. For the aging tests of the special ceramic tape samples, a voltage of 1500 V AC was also applied. All aging tests were conducted in air with the oven temperature set at ~1340°F (727°C).

The bar sample preparation and oven loading procedure was essentially unchanged from that used in the ALMR EM pump insulation life testing program. Several bars (e.g., four or five) were clamped between two unoxidized stainless-steel plates. The applied voltage terminals were attached to the plates and to each bar sample. In the case of the bar leads, the attachment was at a small set screw located at one end of each copper bar (No. 29 drill hole). To insure good electrical contact for the previously cured insulation bar samples, a 0.001 in. (0.025 mm) thick foil of stainless steel was wrapped tightly around the outside of the insulation and fixed at each end with stainless-steel wire. Depending upon the number of samples, several of these bar sample-plate sandwiches were stacked one on top of each other forming a test matrix. The maximum oven loading was about 24 bar samples.

The oven heatup and approach to full applied voltage was done in a gradual and controlled manner. With the samples placed in the oven and the equipment and power and voltage leads and supply equipment checked out, the oven was heated to 125°C and held at that temperature overnight to remove any residual sample moisture. The oven temperature was then raised gradually at a maximum rate of 100°C/h until the specified 1345°F (~730°C) aging temperature was reached. In some cases, depending upon the type of samples and their condition (i.e., cured or uncured) a hold for several hours at a specified temperature (e.g., 500°C) was required to ensure that complete sample curing was obtained. With the oven at the reference aging temperature, the voltage was applied across the bar samples, also in an incremental manner, at a maximum of 250 V per step (rate of voltage increase was just long enough to record all of the sample's leakage currents). This startup phase generally took several days to complete.

Several aging tests were conducted during the preirradiation phase of the program. The original accelerated tests specified in Ref. 2 were slightly modified in order to phase in additional Nextel ceramic tape samples into the program. Therefore, only the splitting mica samples were tested to the specified 500 h. The other white and amber sample aging time was shortened to ~350 h. Other aging tests on the special Nextel and combination insulation materials had aging tests which varied from 270 to 336 h. In addition, very short 1 day aging tests were conducted to assess quickly the performance of bar samples to be inserted in the temperature test.

The data from the aging tests were recorded on a daily basis once the reference applied voltage and temperature had been reached. The oven temperature, the applied voltage, and the sample leakage current were recorded. Also photographs of the samples installed in the oven and the overall test setup were taken for the archival record.

IV. IRRADIATION TEST

A. Overall Description

Irradiation of the bar samples occurred in the J2 thimble of the EBR-II reactor. For in-reactor irradiation testing, the bar samples were placed in a canister made from stainless steel. The canister design and general features are shown in Fig. 5. Internal to the canister was a spacer frame for separating the individual bar samples. After the samples were loaded into the canisters, the canisters were placed in a special glovebox and filled with nitrogen. The glovebox was purged and filled with nitrogen several times to assure removal of air. While in the glovebox, the covers were screwed on the canisters. Sealing was accomplished by means of a metal O-ring. Photographs of the bar sample loading and gas filling in the glovebox are shown in Figs. 6 and 7.

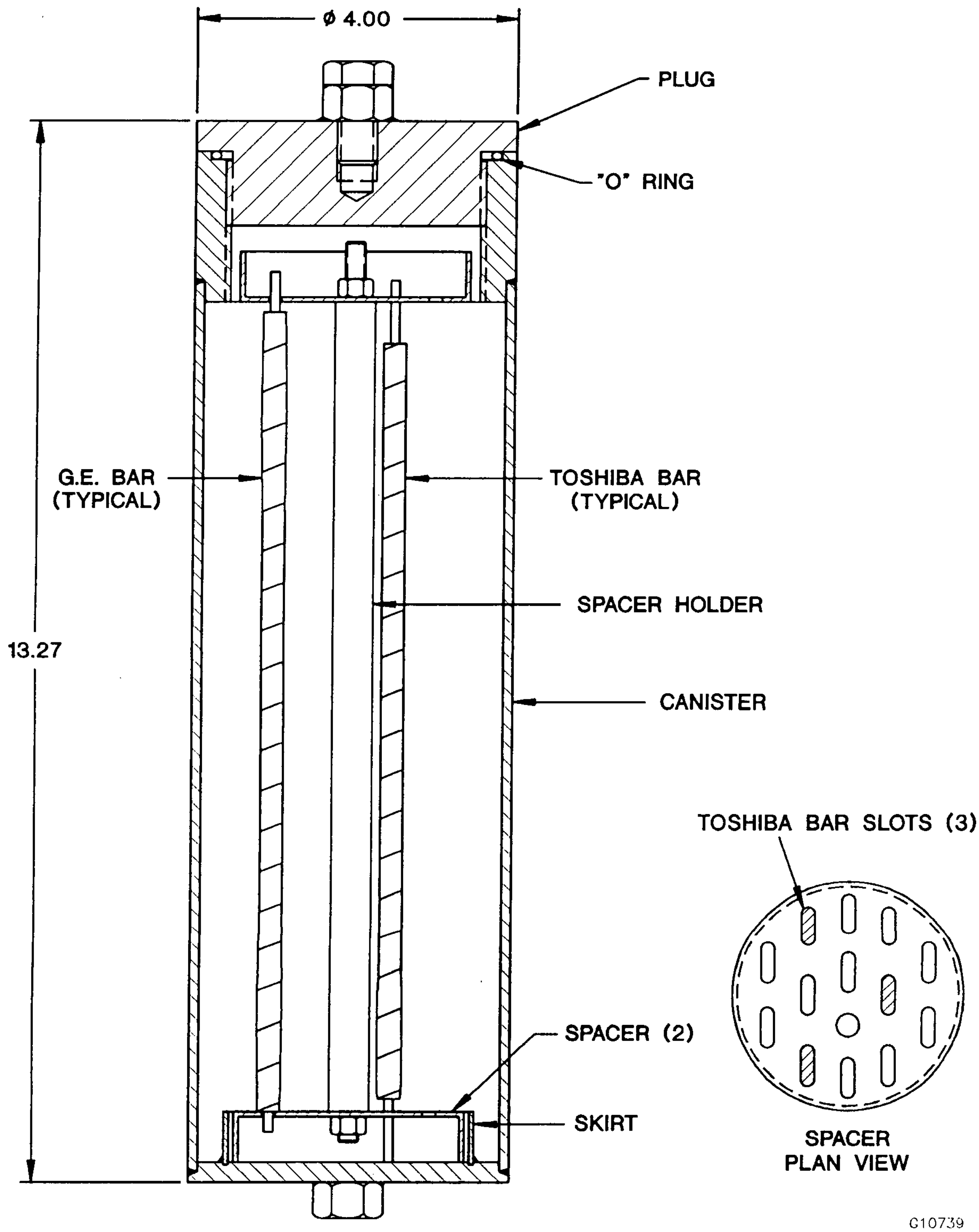


Fig. 5. Bar Sample Canister Design

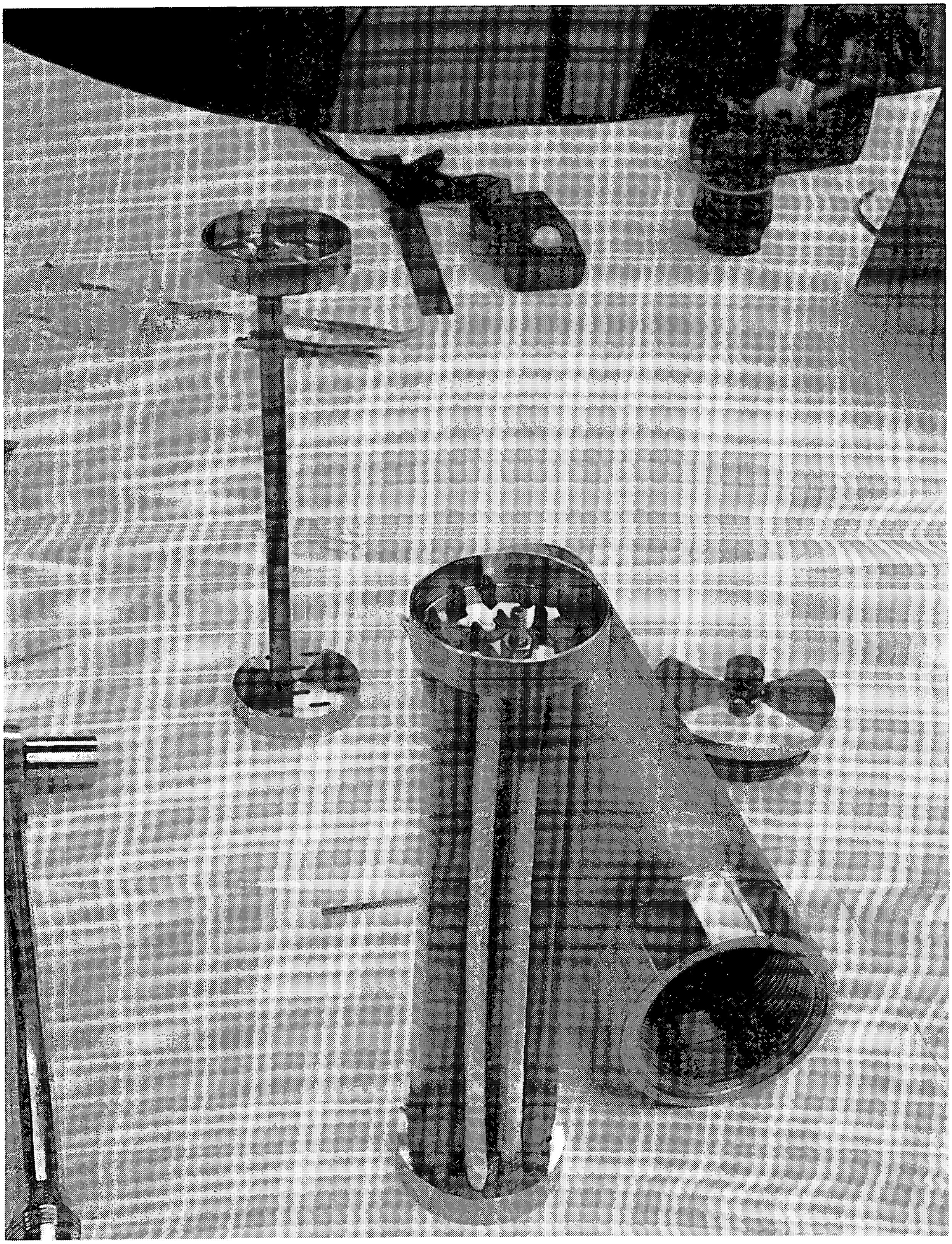


Fig. 6. Bar Samples in Spacer Holder Being Readied for Loading into Canister
(ANL-West Neg. No. DD5215)

Fig 7. Bar Samples Inside Canisters in the Glovebox for Filling With Nitrogen and Sealing (ANL-West Neg. No. DD5212)

B. Experiment Assembly

Three canisters were used for the irradiation portion of the experiment. Each canister contained 13 bar samples. The canisters were held by a canister-carrier assembly that provided the means for inserting them into the reactor and positioning them near the core. The arrangement of the canister-carrier assembly within the J2 thimble and the thimble within the reactor is illustrated in Fig. 8. Photographs of the canister-carrier assembly are shown in Figs. 9 and 10. The lower portion of the canister-carrier assembly with the three canisters held within the carrier is shown in Fig. 9. The entire canister-carrier assembly as it was positioned for insertion into the reactor thimble is shown in Fig. 10.

The temperature histories of the three canisters were recorded by two thermocouples (see Fig. 11) attached to each canister. The neutron flux at the three canister locations was determined by a neutronic calculation. As expected, the top canister was subjected to a specified low fluence and the bottom canister to a high fluence.

C. Assembly Insertion

The lower carrier, which contained the three sample canisters, was assembled to the upper carrier. Two thermocouples were secured to the outside center of each sample canister on opposite sides (one toward the core location and one opposite).

The completed NITF J2 carrier assembly was ready for insertion into the EBR-II Reactor J2 thimble on July 23, 1993. On Monday, July 26, the assembly was attached to the reactor building crane and raised over the J2 thimble. Insertion was accomplished relatively slowly to prevent thermal shock to the assembly. Once the experimental assembly was secured in place, the thermocouple leads were connected for immediate readings. All thermocouples responded properly. EBR-II started up for Run No. 165A on July 29. Reactor criticality was reached at 1726 h. The reactor was at full power of 62.5 MW on July 31 at 1742 h. Run No. 165A concluded at 1748 h on October 7. This run resulted in 66.0 effective full power days (EFPD).

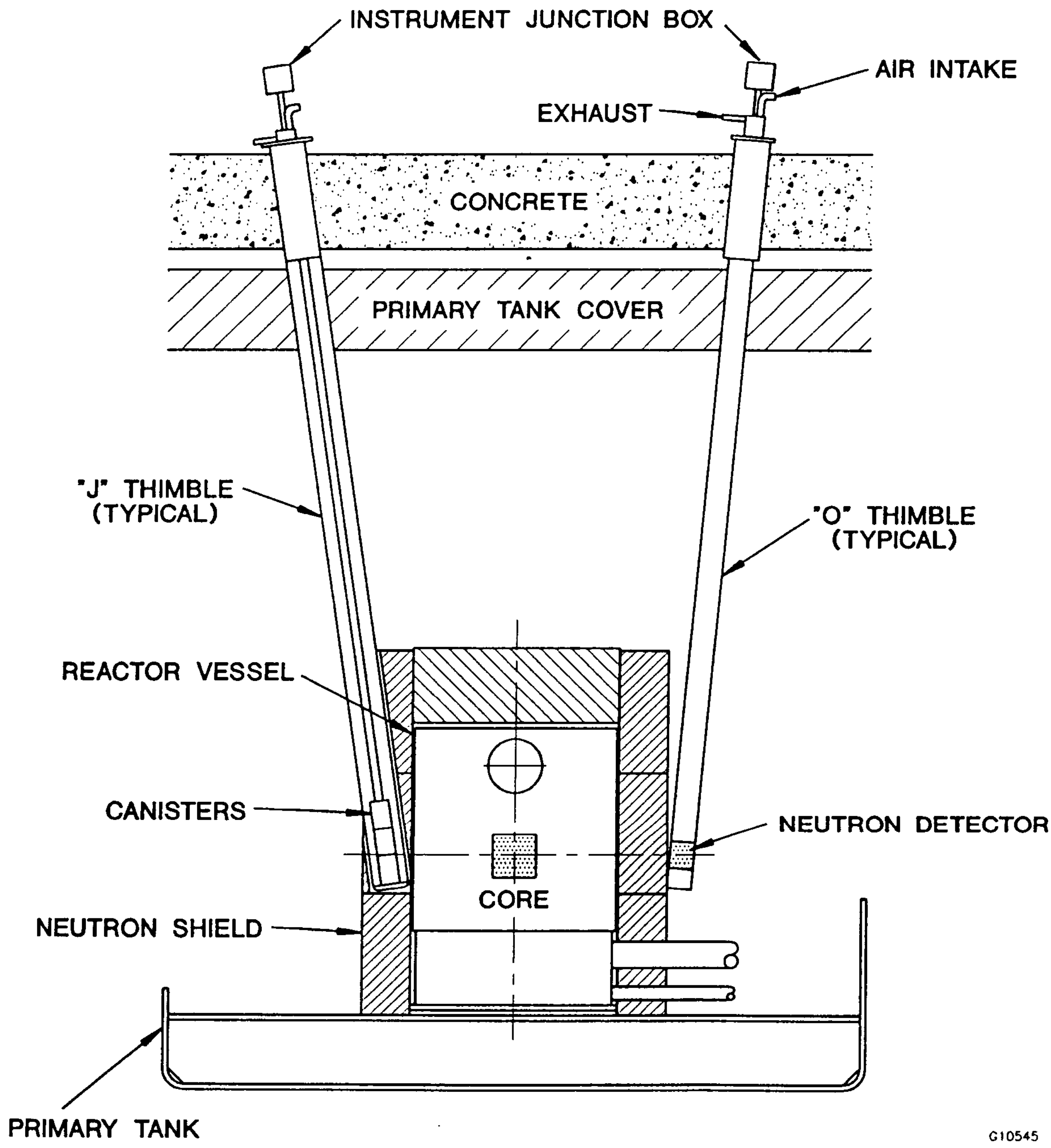


Fig. 8. Arrangement of Canister-carrier Assembly Within the Thimble and Thimble Within Reactor

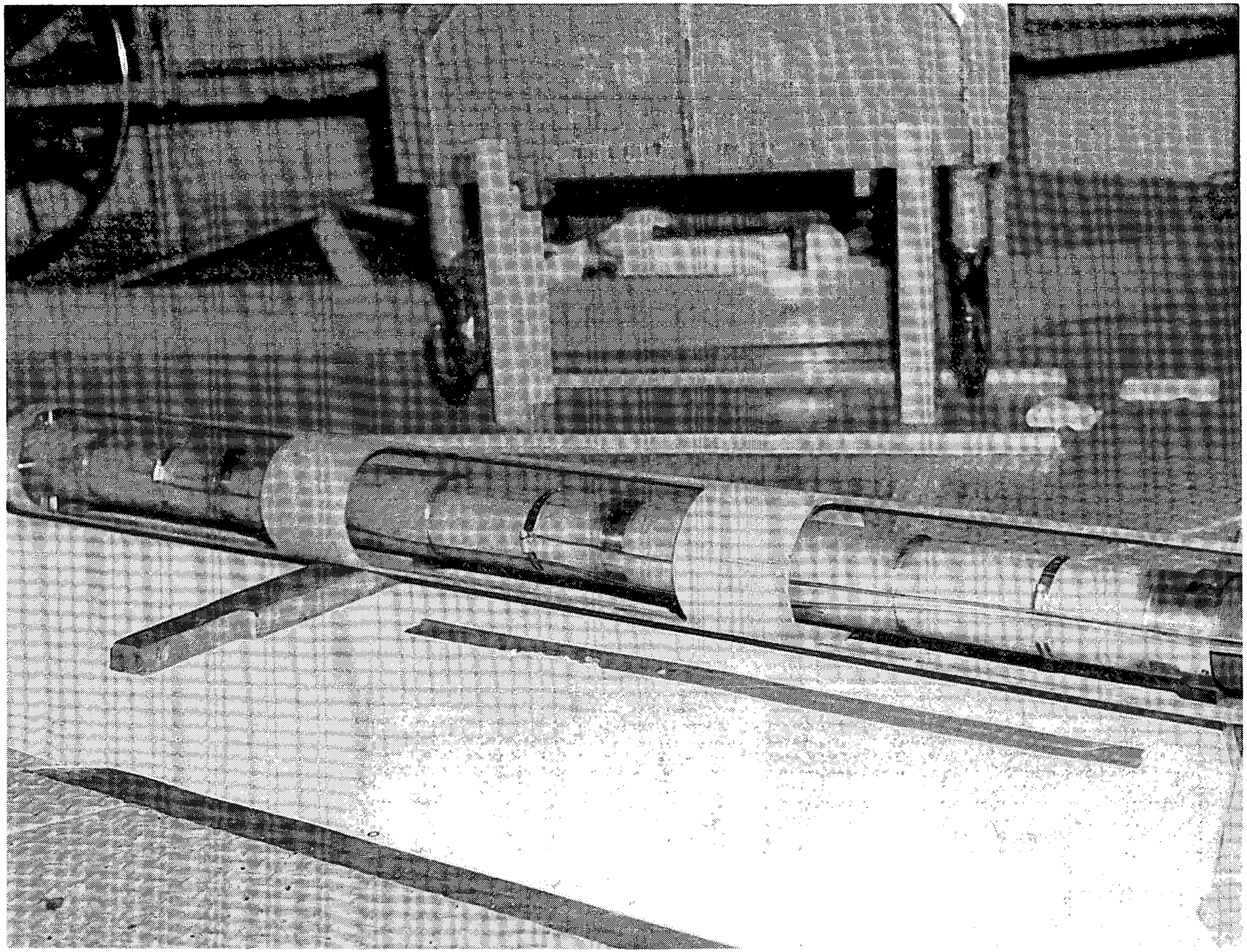


Fig. 9. Lower Portion of Canister-carrier Assembly Showing Thermocouples on All Three Canisters (ANL-West Neg. No. DD5220)

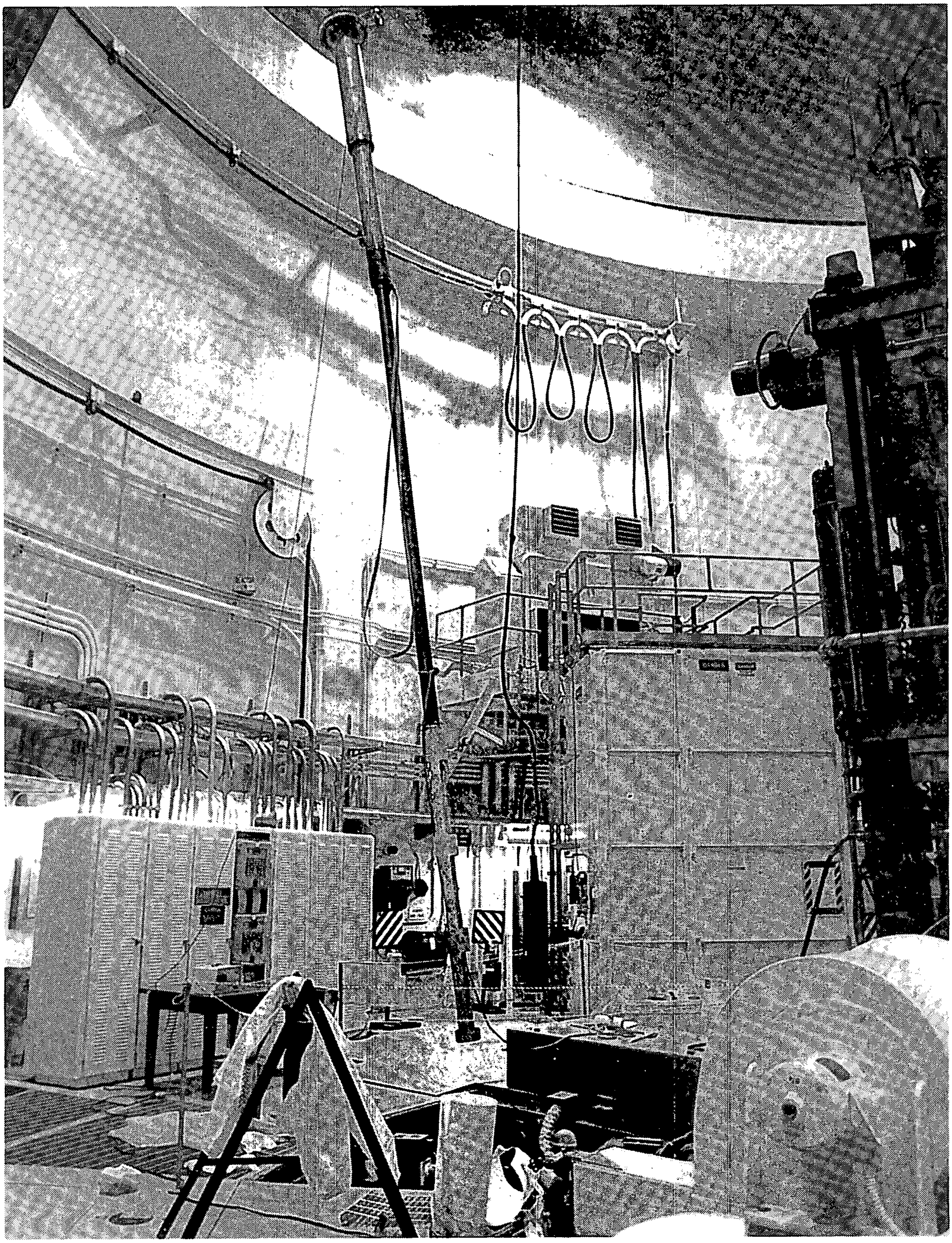


Fig. 10. Canister-carrier Assembly Positioned for Insertion into Reactor Thimble

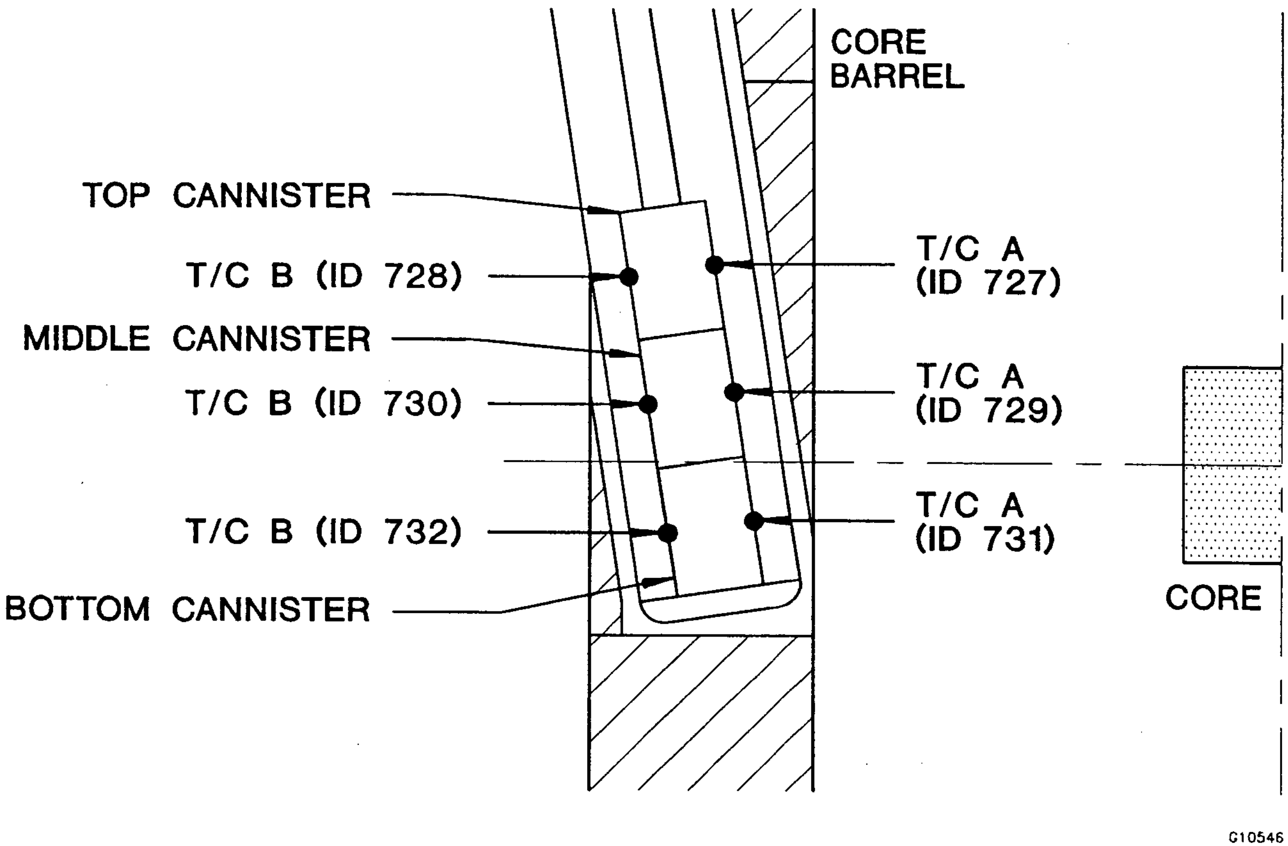


Fig. 11. Canister Thermocouple Location to Measure Canister Temperature in EBR-II

Run No. 166A began on October 30 and was comprised of two run segments due to a loss of instrument air. The final segment concluded at 0427 h on December 1, 1993. Both segments of Run No. 166A provided an additional 26.34 EFPD. The total EFPD for the sample irradiation was 92.34.

D. Assembly and Bar Sample Removal

The NI-10 carrier assembly was removed from the J2 thimble on December 10 and placed directly into the reactor storage pit. A reading of 25 R was taken about 2 ft from the carrier bottom during this process. This high reading required that the samples have a long decay time in the storage pit. A combination of assembly high activity, procedure revision requirements, reactor annual maintenance shutdown, and manpower shortage caused a considerable delay for removal of the bar sample canisters.

On April 13, 1994, the lower assembly was disconnected from the upper assembly. The lower carrier was reading 40 to 70 R between 4 to 8 in. from the surface. This required remote handling of the experiment in the "pentagon". The pentagon is a highly-shielded area of the EBR-II reactor building equipped with a remote manipulator. Additional hardware was fabricated and placed in the pentagon for the lower carrier and canister disassembly. Problems were encountered in removing two of the three canister lids. Eventually, the canisters had to be cut open with a remodeled pipe cutter. On May 16, all bar samples had been removed and placed in their individual locations in the three canisters. All the activated assembly hardware was placed in a container and placed in the storage pit. New air quality orders posed a further problem in obtaining a facility to perform the posttesting of the highly-activated samples. Eventually, the sodium components maintenance shop (SCMS) was approved for the installation of the postirradiation test equipment and new procedures for the posttest handling were developed.

E. In-reactor Environment

1. Temperature

The in-reactor location of the canisters is illustrated in Fig. 11. At this location, the samples were subjected to elevated temperatures. The bottom canister being closest to the core, experienced the highest temperature and the top canister, being the farthest from the core, the lowest temperature. The temperatures of the three canisters were measured by thermocouples. Two thermocouples per canister were used as illustrated in Fig. 11. Each thermocouple was at the canister midlength with one being nearest to the core and the other diametrically opposite. The thermocouples were secured against the exterior surface of the canister. The average canister temperatures during the steady-state 100% reactor power operation were as follows:

Canister	Temperature
Top	830°F (443°C)
Middle	997°F (536°C)
Bottom	1137°F (614°C)

Temperature histories during the in-reactor testing are given in Figs. 12 through 16. Figure 12 shows the entire temperature history for the two operating cycles. Figures 13 through 16 amplify the temperatures during the test to the reactor power and shutdown periods for the two operating cycles. The temperature of the bar samples is estimated to be somewhat higher than the thermocouple reading due to gamma heating of the canister steel and the bar sample copper. Temperatures of the bar sample copper are estimated to be 10 to 20°F (5.6 to 11.1°C) above the thermocouple readings as a result of gamma heating.

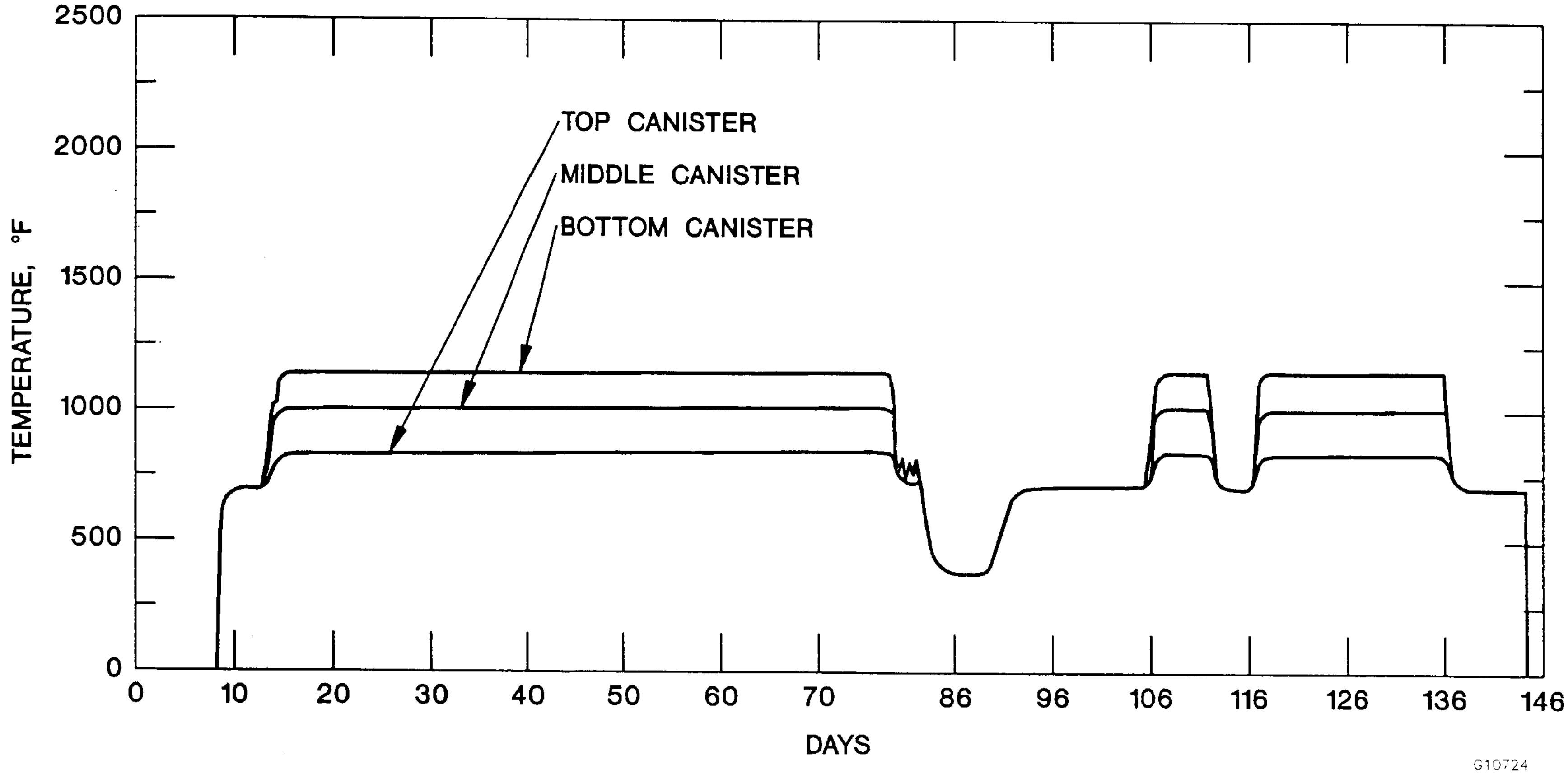


Fig. 12. Entire Temperature History for Two Operating Cycles

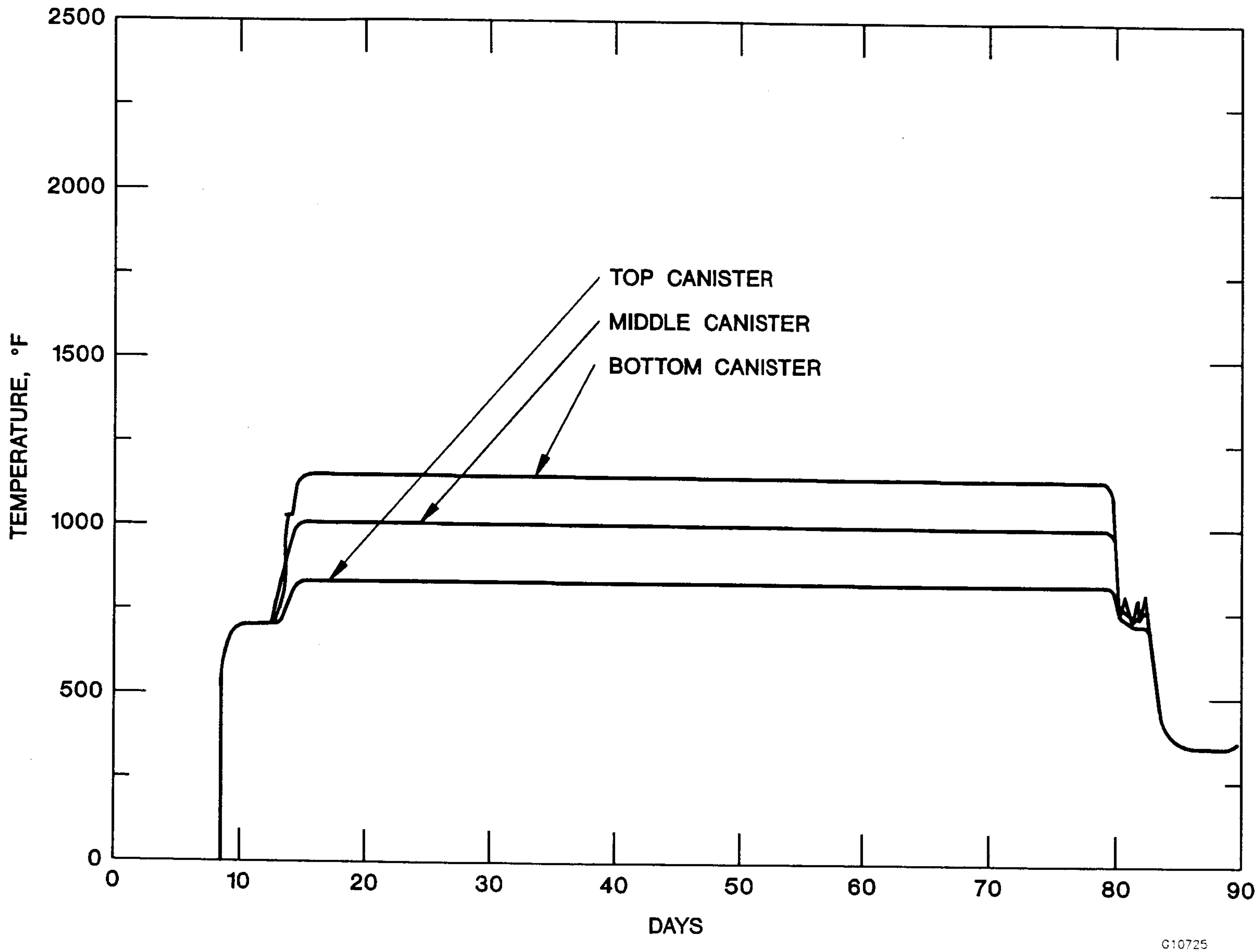


Fig. 13. Cycle 1 Temperature History Amplified

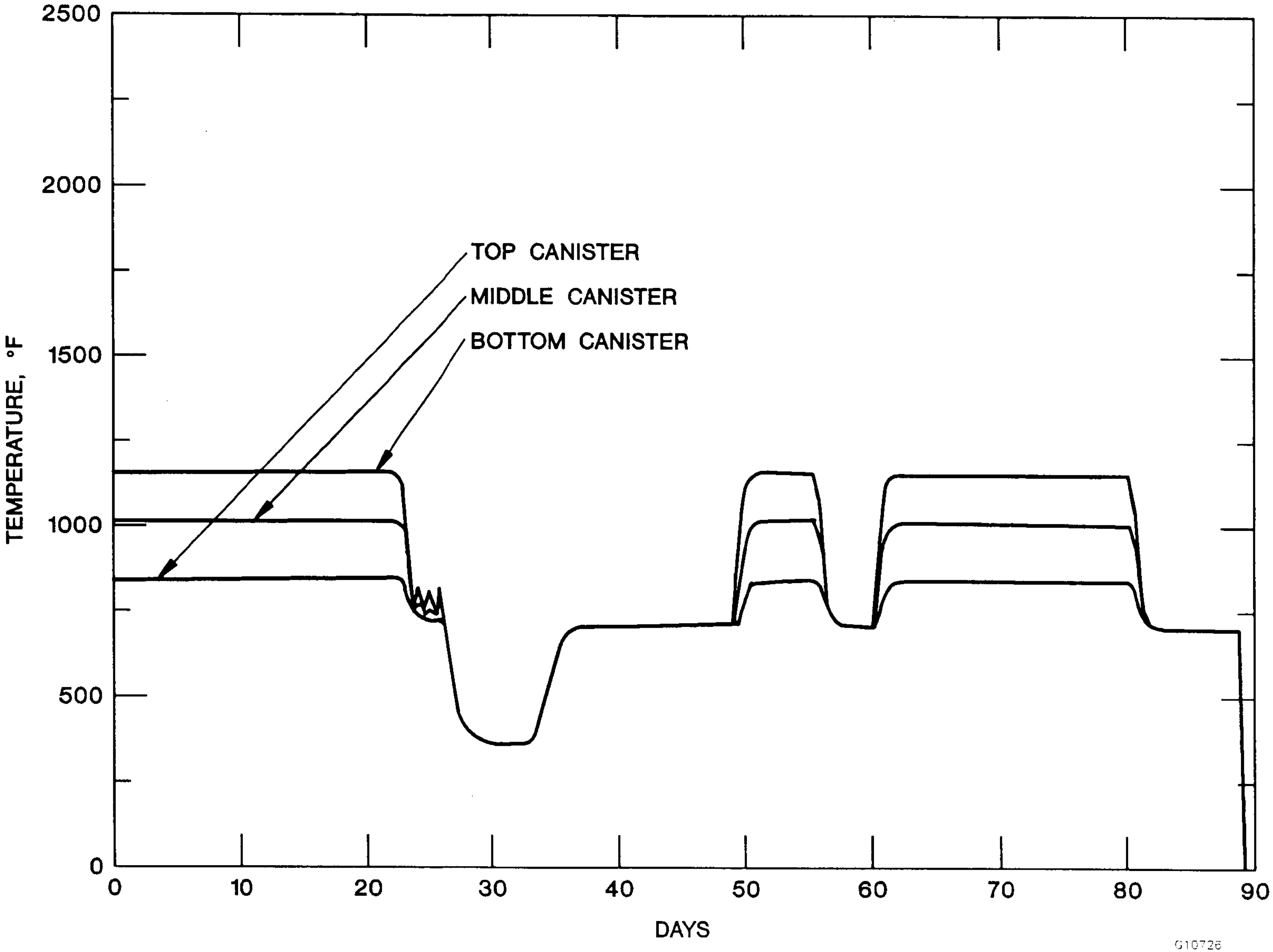


Fig. 14. Cycle 2 Temperature History Amplified

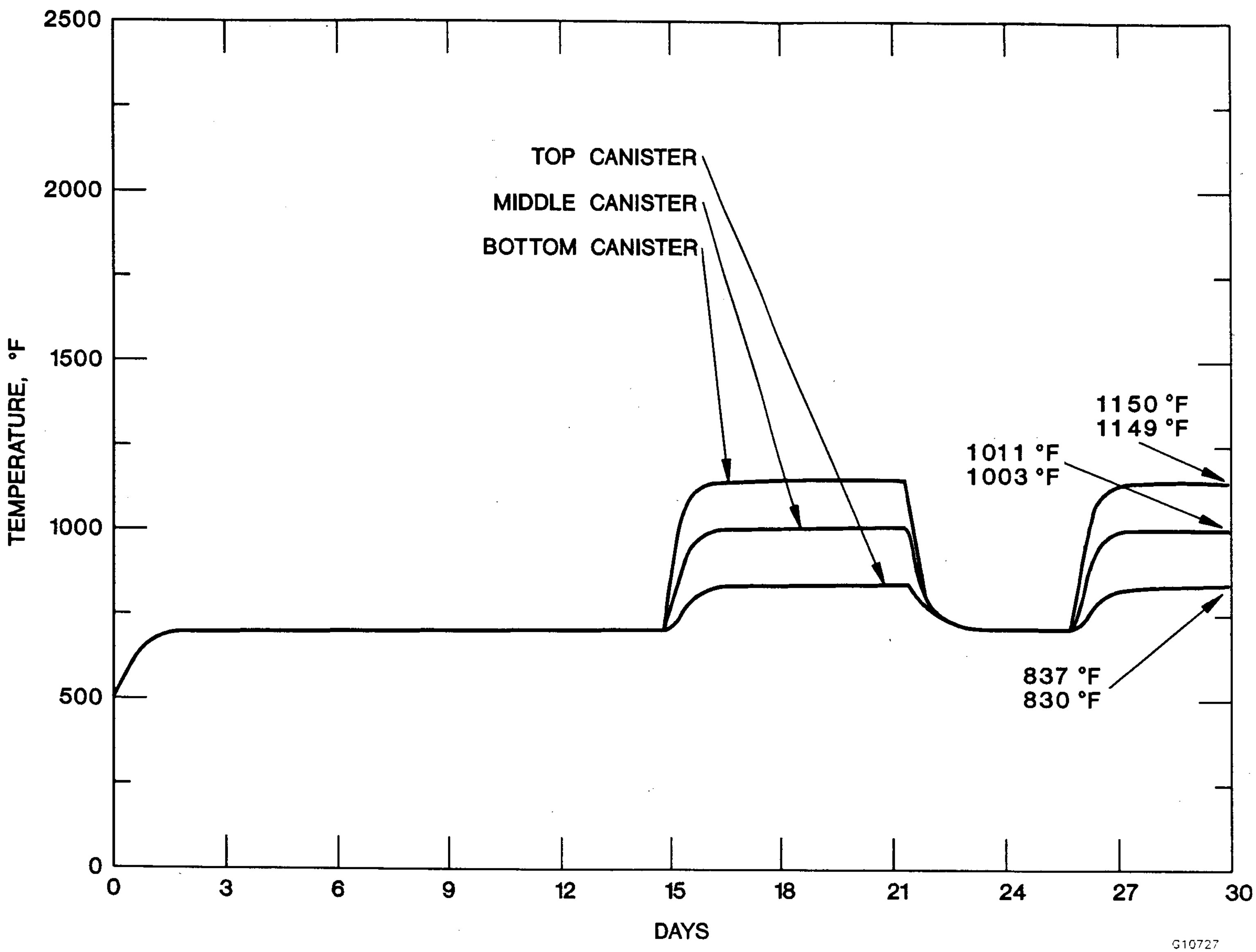


Fig. 15. Temperature History for Cycle 2 Heatup, Power Operation, Scram and Back to Power

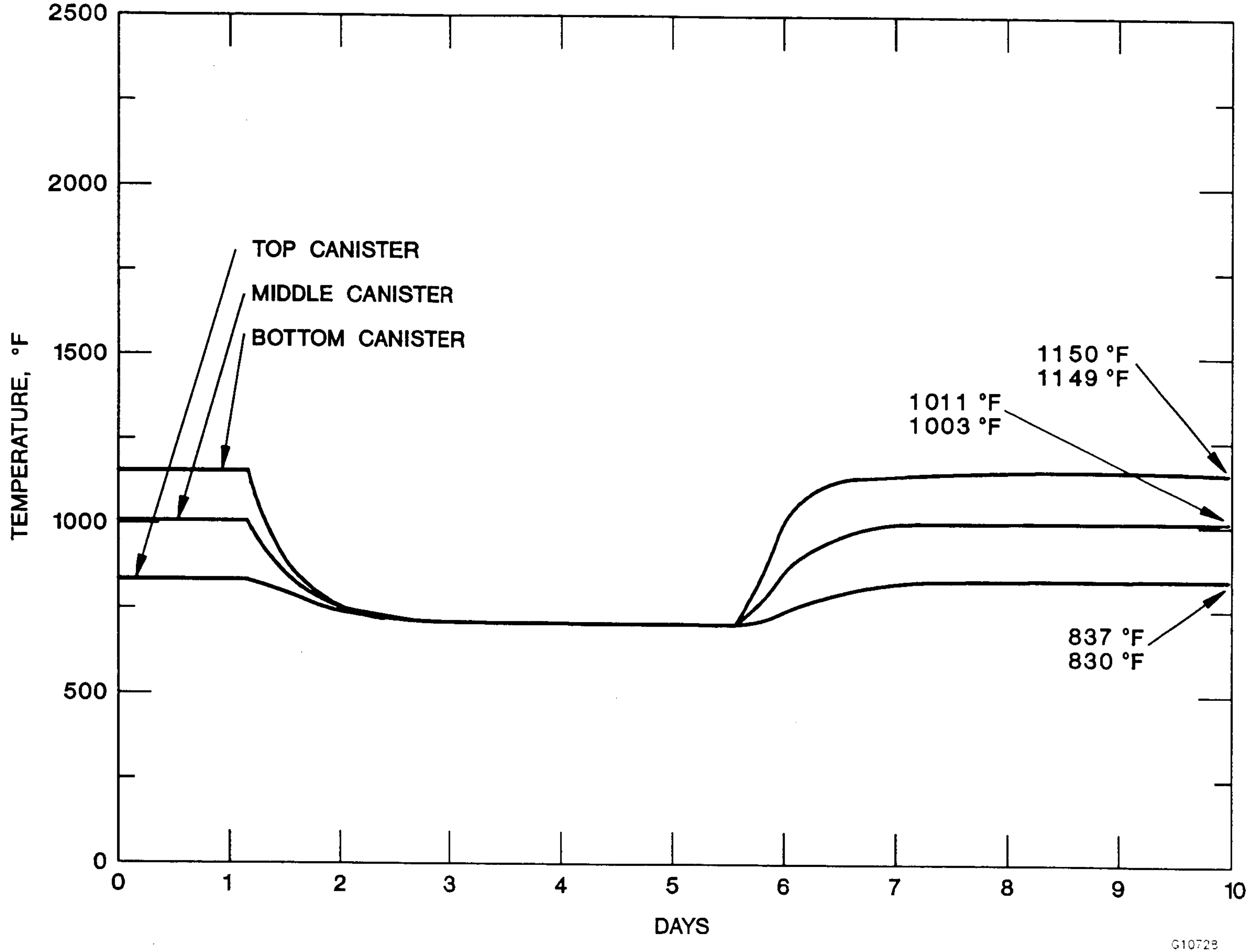


Fig. 16. Cycle 2 Scram Temperature History Amplified

2. Radiation

The calculated flux level at each canister location is shown in Fig. 17. The canisters were in the reactor for two operating cycles and for the shutdown periods between the cycles. A total of 92.34 EFPD of operation and exposure to the full flux level was accumulated. The resulting fluence values are as follows:

Canister	In-reactor Operation	Fluence
Top	92.34 EFPD	3.0×10^{17} n/cm^2
Middle	92.34 EFPD	2.3×10^{18} n/cm^2
Bottom	92.34 EFPD	1.9×10^{19} n/cm^2

These values are close to the targets of 90 EFPD and fluence of between 10^{16} to 10^{18} n/cm^2. Appendix A provides the detailed analysis for flux and fluence estimate.

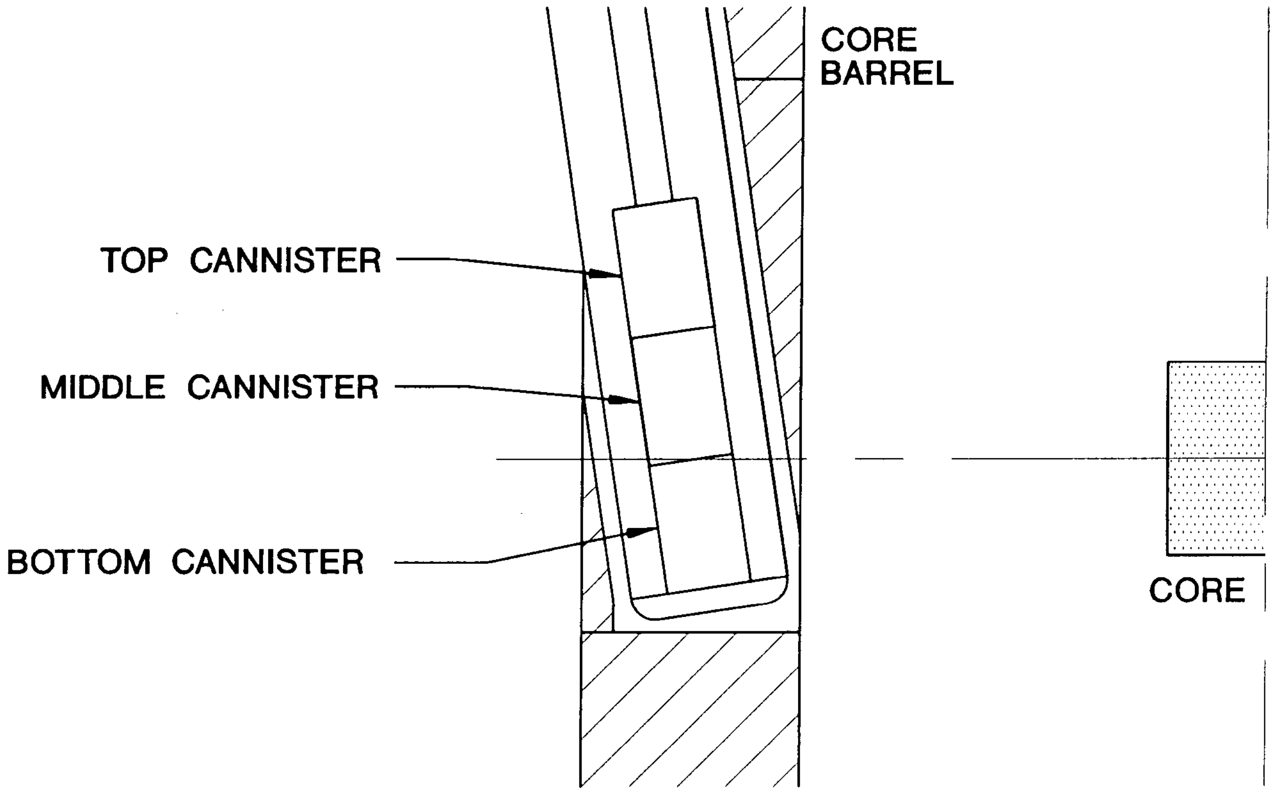
V. POSTIRRADIATION TEST RESULTS

The postirradiation testing was accomplished in two segments. Priorities and a smaller quantity of samples dictated that the Toshiba samples be tested first.

A. Physical Examinations

1. Description

The Toshiba samples were visually examined as they were laid out for the postirradiation testing. They had some slight discoloration, but visually the irradiation environment appeared to have had very little effect on them (see Appendix B). The insulation windings seemed to have held together very well.



CANISTER	FLUX @ 100 % POWER n/cm^2 -s
TOP	3.76×10^{10}
MIDDLE	2.89×10^{11}
BOTTOM	2.38×10^{12}

G10756

Fig. 17. Canister Radiation Response in EBR-II

A group photograph of the six Toshiba samples was taken for reference (see Appendix B). A Mettler Model No. PM2000 balance was used for the weighing and the flat surface of a Mitutoyo digital caliper was used for the dimensional measurements.

The General Electric bar samples were also photographed and examined with the results reported in Appendix B. Figure 3 in Sect. III illustrates the locations where the bar sample dimensions were measured.

2. Test Results

The weights and dimensional measurements of the six Toshiba samples are listed in Table I. The weights and dimensional measurements of the 33 General Electric samples are listed in Table II.

B. Electrical Testing

1. Description

The electrical tests were performed on each bar sample as per the requirements of Ref. 2. These tests were identical to those previously described for the irradiation tests in Sect. III.C.

2. Test Results

The results of the resistance of the Megger tests of the Toshiba samples are listed in Table III.

The results of the resistance of the Megger tests of the General Electric samples are listed in Table IV.

Leakage current readings of the Hipot tests of the Toshiba samples are found in Table V.

TABLE I. Aging Test Results of the Six Toshiba Samples

Sample	Weight (g)	Width and Thickness Dimensions (in.)				
		A	B	C	D	E
Toshiba 1	81.7	0.588	0.507	0.503	0.508	0.467
		0.303	0.259	0.263	0.256	0.262
Toshiba 2	84.3	0.510	0.540	0.534	0.514	0.464
		0.312	0.278	0.265	0.280	0.276
Toshiba 3	84.3	0.567	0.494	0.504	0.494	0.487
		0.307	0.266	0.278	0.287	0.282
Toshiba 4	82.7	0.550	0.495	0.502	0.495	0.468
		0.329	0.275	0.265	0.260	0.262
Toshiba 5	81.7	0.560	0.489	0.494	0.501	0.462
		0.315	0.269	0.260	0.258	0.260
Toshiba 6	84.1	0.531	0.499	0.500	0.503	0.470
		0.286	0.268	0.247	0.269	0.248

TABLE II. Aging Test Results of the 33 General Electric Samples

Sample	Weight (g)	Width and Thickness Dimensions (in.)				
		A	B	C	D	E
N10	78.4	0.537	0.529	0.518	0.509	0.491
		0.333	0.254	0.247	0.242	0.295
N11	80.9	0.493	0.517	0.539	0.532	0.477
		0.244	0.262	0.266	0.267	0.245
N12	82.3	0.508	0.560	0.531	0.530	0.543
		0.283	0.268	0.266	0.268	0.279
N13	81.4	0.466	0.548	0.566	0.515	0.554
		0.247	0.268	0.271	0.265	0.310
N14	81.2	0.534	0.559	0.551	0.521	0.503
		0.294	0.261	0.264	0.258	0.284

TABLE II. (Contd.)

Sample	Weight (g)	Width and Thickness Dimensions (in.)				
		A	B	C	D	E
N15	81.9	0.510	0.541	0.513	0.561	0.458
		0.305	0.262	0.266	0.246	0.282
N16	80.2	0.547	0.532	0.530	0.533	0.492
		0.325	0.261	0.262	0.241	0.299
N17	78.3	0.493	0.514	0.530	0.526	0.536
		0.282	0.239	0.250	0.255	0.330
N18	N/A					
N19	N/A					
2A	84.2	0.498	0.550	0.551	0.549	0.565
		0.283	0.363	0.371	0.369	0.303
3A	88.2	0.569	0.572	0.555	0.578	0.523
		0.331	0.445	0.423	0.442	0.319
G1	86.2	0.562	0.550	0.538	0.546	0.514
		0.340	0.350	0.334	0.345	0.303
G2	86.3	0.551	0.549	0.545	0.553	0.508
		0.330	0.358	0.339	0.351	0.297
G3	86.3	0.528	0.538	0.544	0.526	0.507
		0.333	0.360	0.348	0.330	0.290
G4	80.2	0.542	0.547	0.544	0.555	0.512
		0.316	0.345	0.338	0.356	0.297
G5	89.4	0.568	0.558	0.529	0.534	0.530
		0.375	0.357	0.343	0.334	0.312
G6	90.8	0.565	0.564	0.553	0.566	0.528
		0.354	0.382	0.366	0.368	0.317
G7	87.9	0.590	0.562	0.548	0.548	0.514
		0.360	0.364	0.356	0.365	0.308

TABLE II. (Contd.)

Sample	Weight (g)	Width and Thickness Dimensions (in.)				
		A	B	C	D	E
G8	89.5	0.560	0.556	0.558	0.564	0.549
		0.384	0.368	0.364	0.371	0.329
G9	87.4	0.579	0.554	0.539	0.525	0.514
		0.357	0.356	0.338	0.349	0.297
G10	88.8	0.572	0.554	0.545	0.549	0.523
		0.392	0.375	0.348	0.362	0.289
G11	89.5	0.589	0.585	0.552	0.549	0.538
		0.399	0.395	0.375	0.373	0.310
G12	N/A					
G13	N/A					
G14	85.3	0.523	0.542	0.551	0.539	0.508
		0.326	0.337	0.357	0.365	0.298
G15	N/A					
G16	N/A					
G21	85.0	0.588	0.585	0.619	0.605	0.546
		0.326	0.392	0.386	0.383	0.360
G22	84.5	0.631	0.593	0.589	0.601	0.549
		0.408	0.398	0.377	0.378	0.347
G26	84.9	0.565	0.606	0.611	0.616	0.568
		0.352	0.374	0.368	0.371	0.353
G32	N/A					
G33	80.5	0.540	0.550	0.542	0.558	0.506
		0.300	0.319	0.311	0.339	0.293

TABLE III. Pre-and Postaging Megger Electrical Testing of Toshiba Samples

Sample	Preaging Megger Test GΩ	Postaging Megger Test GΩ
Toshiba 1	>100	>100
Toshiba 2	>100	> 100
Toshiba 3	80	80
Toshiba 4	>100	> 100
Toshiba 5	>100	> 100
Toshiba 6	>100	> 100

TABLE IV. Pre-and Postaging Megger Electrical Testing of General Electric Samples

Sample	Preaging Megger Test GΩ	Postaging Megger Test GΩ
N10	>100	>100
N11	>100	>100
N12	>100	N/A
N13	>100	>100
N14	>100	60
N15	>100	>100
N16	>100	N/A
N17	>100	>100
N18	N/A	N/A
N19	N/A	N/A
2A	>100	>100
3A	>100	N/A
G1	>100	>100
G2	>100	>100
G3	>100	>100

TABLE IV. (Contd.)

Sample	Preaging Megger Test GΩ	Postaging Megger Test GΩ
G4	>100	N/A
G5	>100	N/A
G6	>100	>100
G7	>100	>100
G8	>100	>100
G9	>100	N/A
G10	>100	N/A
G11	>100	N/A
G12	N/A	N/A
G13	N/A	N/A
G14	>100	>100
G15	N/A	N/A
G16	N/A	N/A
G21	>100	>100
G22	>100	>100
G26	>100	>100
G32	N/A	N/A
G33	>100	>100

TABLE V. Pre-and Postaging Hipot Electrical Testing of Toshiba Samples

Sample	Preaging Hipot Test mA	Postaging Hipot Test mA
Toshiba 1	0.244	0.187
Toshiba 2	0.204	0.186
Toshiba 3	0.310[a]	0.192[b]
Toshiba 4	0.198	0.193
Toshiba 5	0.217	0.186
Toshiba 6	0.216	0.189

[a]Read 0.310 mA, then arced to 0 indicating failure.
[b]Reading 0.192 mA, audible arcing, power shut off.

Leakage current readings of the Hipot tests of the General Electric samples are found in Table VI.

C. Accelerated Age Testing

1. Description

The aging test of the Toshiba samples was conducted at approximately 1345°F and 600 V AC for 503 h.

The aging test of the General Electric samples was conducted at approximately 1345°F and 1500 V AC for 355 h.

2. Test Results

Data taken during the aging tests for the Toshiba samples are shown in Table VII.

Data taken during the aging tests for the Toshiba samples are shown in Table VIII.

TABLE VI. Pre-and Postaging Hipot Electrical Testing of General Electric Samples

Sample	Preaging Hipot Test mA	Postaging Hipot Test mA
N10	2600 V*	2600 V
N11	2800 V*	2600 V*
N12	2600 V*	N/A
N13	1800 V*	2200 V*
N14	1700 V*	1200 V*
N15	2400 V*	2400 V*
N16	0.200	N/A
N17	2200 V*	1400 V*
N18	1900 V*	N/A
N19	2400 V*	N/A
2A	0.196	0.184
3A	0.191	N/A
G1	0.187	0.211
G2	0.181	0.180
G3	0.189	0.181
G4	0.182	N/A
G5	2600 V*	N/A
G6	0.200	0.189
G7	0.207	0.196
G8	0.201	0.184
G9	0.197	N/A
G10	0.193	N/A
G11	0.197	N/A
G12	0.183	N/A
G13	0.181	N/A
G14	0.174	0.180
G15	0.184	N/A

TABLE VI. (Contd.)

Sample	Preaging Hipot Test mA	Postaging Hipot Test mA
G16	0.192	N/A
G21	0.181	0.174
G22	0.181	0.181
G26	0.195	0.191
G32	0.187	N/A
G33	0.184	0.182

*Sample failed, audibly sizzling and buzzing.

Test was then done in 500 V increments to see if the voltage level at failure could be determined. Approximate voltage at failure is recorded in the table below.

Sample	500 V	1000 V	1500 V	2000 V	2500 V	Failure
Preaging						
N10[a]	0.027	0.054	0.084	0.116	0.146	X ~ 2600 V
N11[a]	0.057	0.089	0.115	0.145	0.171	0.204
G5[b]	0.058	0.085	0.115	0.146	0.176	0.206
N12[b]	0.054	0.085	0.115	0.141	0.169	X ~ 2600 V
3A	0.056	0.088	0.117	0.144	0.177	X ~ 2600 V
N13	0.052	0.074	0.116	X	X	X ~ 1800 V
N14	0.053	0.086	0.113	X	X	X ~ 1700 V
N15	0.051	0.086	0.116	0.151	X	X ~ 2400 V
N17	0.027	0.059	0.091	0.123	X	X ~ 2000 V
N18	0.027	0.064	0.102	X	X	X ~ 1900 V
N19	0.033	0.064	0.099	0.134	X	X ~ 2400 V
Postaging						
N10	0.025	0.053	0.087	0.121	0.146	X ~ 2600 V
N11	0.052	0.088	0.111	0.122	0.150	X ~ 2600 V
N13	0.031	0.061	0.097	0.139	X	X ~ 2200 V

TABLE (Contd.)

Sample	500 V	1000 V	1500 V	2000 V	2500 V	Failure
N14	0.030	0.064	X	X	X	X ~ 1200 V
N15	0.038	0.064	0.102	0.139	X	X ~ 2400 V
N17	0.028	0.058	X	X	X	X ~ 1400 V

[a]Only failed sample from first canister checked at 500 V increments at the time.
[b]Rechecked with second canister of samples at a later date.

TABLE VII. Posttest Accelerated Aging Testing of the Toshiba Samples

Elapsed Time (h)	Applied Voltage (V)	Temp (°F)	Leakage Current in mA			
			Sample 1	Sample 2	Sample 4	Sample 5
0	594	1343	0.670	0.609	0.640	0.751
17	610	1347	0.627	0.638	0.707	0.726
92	605	1346	0.697	0.668	0.635	0.704
114	604	1351	0.646	0.675	0.473	0.669
138	598	1349	0.603	0.698	0.400	0.624
187	601	1353	0.501	0.719	0.374	0.462
263	594	1348	0.452	0.709	0.329	0.450
282	603	1345	0.448	0.738	0.352	0.475
306	605	1353	0.426	0.723	0.364	0.490
330	605	1346	0.410	0.713	0.371	0.485
354	600	1344	0.388	0.687	0.370	0.482
427	593	1345	0.368	0.680	0.358	0.459
450	608	1353	0.365	0.668	0.374	0.477
475	606	1345	0.366	0.671	0.372	0.525
503	605	1344	0.361	0.668	0.363	0.481

TABLE VIII. Posttest Accelerated Aging Testing of the General Electric Samples

Elapsed Time (h)	Applied Voltage (V)	Temp (°F)	Leakage Current in mA							
			Sample N10	Sample N11	Sample N13	Sample N14	Sample N15	Sample 2A	Sample G1	Sample G2
	0	250	23 November 14:52 h							
	0	500	23 November 08:50 h							
	0	750	23 November 09:17 h							
	0	1000	23 November 09:31 h							
	0	1250	23 November 09:50 h							
	250	1346	0.012	0.012	0.012	0.012	0.012	1.31	0.88	0.001
	500	1346	0.012	0.012	0.013	0.013	0.014	2.47	1.70	0.001
	750	1346	0.012	0.013	0.013	0.013	0.013	3.62	2.53	0.002
	1000	1346	0.013	0.013	0.013	0.013	0.013	4.70	3.40	0.003
	1250	1346	0.013	0.014	0.016	0.017	0.016	5.78	4.41	0.004
0	1500	1346	0.013	0.013	0.013	0.017	0.014	7.11	5.54	0.005
120	1520	1346	0.013	0.012	0.012	0.014	0.013	8.73	6.20	0.013
144	1520	1346	0.012	0.012	0.012	0.013	0.012	8.99	6.00	0.012
168	1520	1346	0.012	0.012	0.012	0.013	0.013	9.20	5.75	0.012
192	1530	1346	0.012	0.012	0.012	0.013	0.013	9.30	5.64	0.012
216	1530	1346	0.012	0.012	0.013	0.014	0.013	9.39	5.57	0.012
288	1530	1346	0.012	0.012	0.012	0.014	0.013	9.79	5.54	0.012
312	1520	1346	0.012	0.012	0.013	0.014	0.013	9.95	5.53	0.012
336	1530	1346	0.012	0.012	0.013	0.012	0.012	9.90	5.90	0.012
355	1530	1346	0.012	0.012	0.012	0.013	0.012	10.19	6.20	0.012

TABLE VIII. (Contd.)

Elapsed Time (h)	Applied Voltage (V)	Temp °F	Leakage Current in mA						
			Sample G3	Sample G6	Sample G7	Sample G8	Sample G21	Sample G22	Sample G26
	0	250	22 November 14:52 h						
	0	500	23 November 08:50 h						
	0	750	23 November 09:17 h						
	0	1000	23 November 09:31 h						
	0	1250	23 November 09:50 h						
	250	1346	0.96	0.001	0.012	0.001	7.76	0.000	0.001
	500	1346	1.82	0.002	0.013	0.003	15.64	0.002	0.002
	750	1346	2.77	0.003	0.012	0.004	23.9	0.003	0.003
	1000	1346	3.73	0.005	0.013	0.005	32.2	0.004	0.004
	1250	1346	4.78	0.006	0.016	0.006	41.7	0.005	0.006
0	1500	1346	6.02	0.013	0.014	0.014	53.6	0.006	0.014
120	1520	1346	6.58	0.012	0.013	0.013	52.6	0.013	0.013
144	1520	1346	6.40	0.012	0.012	0.012	52.5	0.012	0.012
168	1520	1346	6.00	0.012	0.012	0.012	52.5	0.012	0.012
192	1530	1346	6.00	0.012	0.013	0.013	52.9	0.012	0.013
216	1530	1346	6.00	0.012	0.013	0.013	54.0	0.012	0.013
288	1530	1346	6.01	0.012	0.012	0.013	54.2	0.012	0.013
312	1520	1346	5.89	0.012	0.013	0.013	53.7	0.012	0.012
336	1530	1346	6.20	0.012	0.012	0.012	54.0	0.012	0.013
355	1530	1346	5.54	0.012	0.012	0.012	53.4	0.012	0.012

TABLE VIII. (Contd.)

Elapsed Time (h)	Applied Voltage (V)	Temp (°F)	Leakage Current in mA		
			Sample N17	Sample G33	Sample G14
	0	250	16 Jan 1995 9:00 h		
	0	500	16 Jan 1995 10:00 h		
	0	750	16 Jan 1995 10:30 h		
	0	1000	16 Jan 1995 11:00 h		
	0	1250	16 Jan 1995 11:30 h		
	0	1346	16 Jan 1995 12:00 h		
	250	1346	0.007	0.012	0.012
	500	1346	0.015	0.012	0.012
	750	1346	0.012	0.012	0.012
	1000	1346	0.012	0.012	0.012
	1250	1346	0.012	0.012	0.012
0	1500	1346	0.012	0.012	0.012

TABLE VIII. (Contd.)

Elapsed Time (h)	Applied Voltage (V)	Temp (°F)	Leakage Current in mA		
			Sample N17	Sample G33	Sample G14
17	1500	1346	0.013	0.012	0.012
41	1500	1346	0.012	0.012	0.012
65	1500	1346	0.012	0.012	0.012
89	1500	1346	0.011	0.011	0.011
161	1500	1346	0.015	0.015	0.015
185	1500	1346	0.016	0.016	0.016
209	1500	1346	0.014	0.014	0.014
233	1500	1346	0.013	0.013	0.013
257	1500	1346	0.013	0.013	0.013
329	1500	1346	0.012	0.011	0.011
353	1500	1346	0.011	0.011	0.011
355	1500	1346	-	-	-

VI. TEMPERATURE TEST

A. Overall Description

As part of this EM insulation bar sample irradiation program, a controlled temperature test was conducted in an oven at ANL-East. This test used a test canister (Canister No. 4) which was identical to the three canisters containing the bar samples irradiated in the J2 thimble of EBR-II. This fourth canister containing 13 bar samples was sealed with 1 atm of nitrogen in the welding glovebox. This canister was placed in an oven (Oven No. 4 at ANL-East) with the temperature history set to mimic that obtained in the highest irradiation canister (i.e., lower canister No. 3). To insure a pure nitrogen atmosphere within the canister, the glovebox was purged with pure bottled nitrogen gas three times before the canister lid was secured. Based on the results of previous test closures, a torque of 70 ft-lb when applied to the canister lid was sufficient to insure a leak-tight lid closure seal. A gas sample of the final glovebox (i.e., canister) atmosphere was taken for archival purposes. Before and after subjecting the bar samples to the actual oven temperature test, several physical and electrical tests and measurements were conducted on the samples. In addition, both a before and after accelerated aging test were conducted in an air oven at temperature and voltage.

Shown in Table IX are the number and type of each of the insulation bar samples that were included in the temperature test. The 13 samples included representatives from each of the five EM pump insulation types included in the irradiation program. As indicated in Table IX, the temperature test samples consisted of three Amber Mica/SECON-5 bars, three Toshiba (splitting mica)/silicon binder bars, three Nextel 440 (ceramic tape)/boron nitride binder bars, two white mica/SECON-5 binder bars, and two amber mica/boron nitride binder bars. For a detailed description of these bar samples, including the chemical composition of the various constituents, Ref. 1 should be consulted.

TABLE IX. Temperature Test Bar Sample Identification

Bar Sample Type	Insulation Bar Sample Designation
Amber/SEC	G17, G18, G19
Toshiba/Si	9, 10, 11
440/BN	N20, N21, N22
White/SEC	G37, G38
Amber/BN	3A-92, 4A

Key

Amber/SEC = Amber Mica/SECON 5 Binder
Toshiba/Si = Splitting Mica/Silicon Binder
440/BN = Nextel 440/Boron Nitride Binder
White/SEC = White Mica/SECON 5 Binder
Amber/BN = Amber Mica/Boron Nitride Binder

The various examinations, test phases and their sequence for each of the 13 bar samples included in the temperature test are provided in Table X. As Table X indicates, the temperature test consisted of essentially nine phases or steps beginning with an initial sample examination and concluding with a final examination of the samples. Also, it should be noted that before and after the actual temperature test an accelerated aging test and several Megger and Hipot electrical measurements were made on some of the samples. As per the test plan of Ref. 2 and subsequent instructions based on the needs of the substituted or replacement bar samples (see Ref. 1), all of the samples did not undergo the complete test sequence. The replacement Nextel 440/BN and Amber/BN bar samples were uncured and therefore were not subjected to the set of initial examinations and tests (see Table X).

B. Temperature Test History

The objective of the temperature test was to simulate the conditions that the EBR-II bar samples experienced but without the influence of the neutron irradiation. The hottest in-reactor canister (i.e., lower canister No. 3) was chosen as the reference canister in an attempt to reproduce the severest thermal conditions that the EM bar samples had experienced. The temperature

TABLE X. Temperature Test Sequence and Phases

Test Phase	Test Description	Amber/SEC			Toshiba/Si			440/BN			White/SEC		Amber/BN	
		G17	G18	G19	9	10	11	N20	N21	N22	G37	G38	3A	4A
1	Initial Examination	X	X	X	X	X	X	NT	NT	NT	X	X	NT	NT
2	First Megger and Hipot	X	X	X	X	X	X	NT	NT	NT	X	X	NT	NT
3	First Aging Oven Test	X	NA	NA	X	X	X	X	NA	NA	X	NA	X	NA
4	Second Megger and Hipot	X	NA	NA	X	X	X	NT	NA	NA	X	NA	NT	NA
5	Temperature Oven Test	X	X	X	X	X	X	X	X	X	X	X	X	X
6	Third Megger and Hipot	X	X	X	X	X	X	X	X	X	X	X	X	X
7	Second Aging Oven Test	X	NA	NA	X	X	X	X	NA	NA	X	NA	X	NA
8	Fourth Megger and Hipot	X	NA	NA	X	X	X	X	NA	NA	X	NA	X	NA
9	Final Examination	X	X	X	X	X	X	X	X	X	X	X	X	X

Key

X = Performed the test or examination.
NA = Not aged or tested as per "Test Plan" instructions.
NT = Not tested or aged as received initially wet (uncured).

of the canisters in the J2 thimble of EBR-II were recorded with two thermocouples attached to the outside of each canister. In order to mimic the in-reactor temperature history, an attempt was made to simulate in a general way the temperature history experienced in-reactor. This required a time lag between the thermal conditions in-reactor and those in the No. 4 Oven containing the temperature test samples. The time delay in this temperature simulation was about 10 days.

The temperature history that the Canister No. 4 samples experienced during the temperature test (see Test Phase 5 of Table X) is presented in Fig. 18. Evident in the temperature history of Fig. 18 is the attempt to simulate the shutdowns and startups associated with the actual EBR-II operating cycles. The reference full-power lower Canister No. 3 temperature was 616°C (1140°F). The total time at or slightly above this temperature was ~83 days with the integrated time at this power (i.e., integral under Fig. 18 curve divided by 616°C) being ~103 days. This temperature test temperature history is slightly different than but brackets the 92.5 full power days experienced by the samples in the irradiation program (see Sect. IV).

C. <u>Pretemperature Test Results</u>

The pretemperature test program which was conducted on the temperature test samples followed the procedures described previously in Sect. III. The pretemperature test program consisted of essentially three parts: (1) physical examinations, (2) electrical testing, and (3) accelerated aging. As identified in Table X, not all of the 13 temperature test bar samples were subjected to these pretemperature tests. The results and data obtained for those samples that were tested are presented in the next several subsections.

1. <u>Physical Examination</u>

The physical examination of the bar samples consisted of a visual inspection, a weighing, and dimensional measurements. Photographs of each bar sample were also taken both after the initial examination and after the first aging test. These photographs are presented in Appendix B.

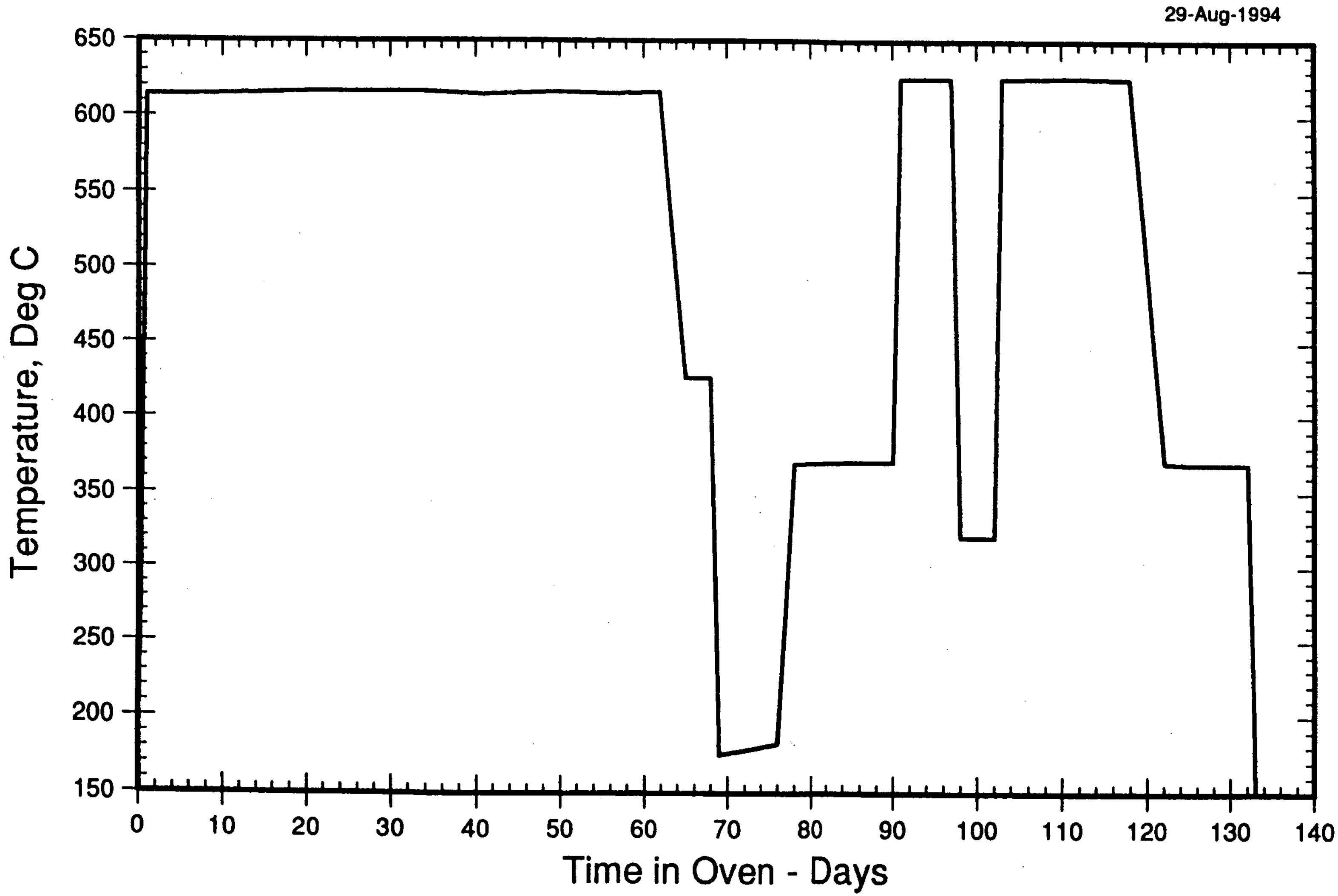


Fig. 18. Temperature Test Temperature History

The results of the initial examination of the temperature test bar samples are shown in Table XI.

2. Electrical Testing

The electrical testing consisted of the standard electrical insulation Megger and Hipot measurements. The sample preparation and measurement procedures were described previously in Sect. III. These pretemperature electrical tests were performed both before and after the initial, or first, accelerated aging oven test.

In Table XII the results of the pretemperature electrical tests are presented.

3. Accelerated Age Testing

The initial, or first, pretemperature accelerated aging test on the 13 bar samples was conducted in the air ovens at ANL-East at temperature and voltage. A description of the methods and procedures is described in Sect. III. The temperature of the samples during the aging test was established at ~730°C. The voltage impressed across the samples insulation was 600 V for the three Toshiba samples and 1500 V for the other remaining four samples that were age tested (see Table X). The aging time varied also with the three Toshiba samples experiencing ~500 h, the three GE mica samples experiencing ~350 h, and the single Nextel samples ran for only a short time ~46 h.

The leakage current results for this first pretemperature aging test are presented in Tables XIII, XIV and XV for the Toshiba samples, the GE mica samples, and the GE Nextel samples, respectively.

D. Posttemperature Test Results

The posttemperature examinations and testing program essentially followed the requirements as specified in the program test plan of Ref. 2. The posttemperature test sequence and phases are shown as items 6 through 9 in Table X.

TABLE XI. Temperature Test Initial Examinations

Sample Number	Total Bar Weight (g)	Insulation Length (in.)	Insulation Areal Dimensions* (in.)	Visual Observartions
G17	88.6	~10	0.570/0.369, 0.549/0.377, 0.567/0.358, 0.540/0.379, 0.533/0.308	Overlapped tape. Overall beige color from Secon-5. Some flaking of Secon especially near numbered end revealing silvery under tape.
G18	90.7	~10	0.581/0.380, 0.567/0.392, 0.557/0.377, 0.549/0.414, 0.519/0.323	Overlapped tape. Overall beige color from Secon-5 coating. Some minor flaking of Secon along entire length of sample revealing silvery tape beneath Secon binder.
G19	90.5	~10	0.605/0.374, 0.568/0.411, 0.553/0.395, 0.537/0.389, 0.528/0.322	Overlapping tape. Overall beige color appearance from Secon-5 binder coating. Very minor flaking of the Secon revealing small areas of silvery tape beneath Secon coating.
9	83.5	~10	0.555/0.271, 0.520/0.277, 0.506/0.265, 0.493/0.259, 0.477/0.232	White woven mica insulation, potted ~1 in. from either end. Insulation not frayed.
10	83.3	~10	0.509/0.274, 0.508/0.289, 0.520/0.291, 0.520/0.301, 0.444/0.222	Appearance the same as bar sample No. 9 except potting on the numbered end extends part-way past 1 in.
11	83.4	~10	0.571/0.256, 0.506/0.261, 0.504/0.277, 0.505/0.281, 0.462/0.218	White woven mica insulation, potted ~1-1/8 in. from unnumbered end, 1 in. from numbered end. Insulation not frayed.
N20	Not Measured	Not Measured	Not Measured	Not Visually Inspected.
N21	Not Measured	Not Measured	Not Measured	Not Visually Inspected.

TABLE XI. (Contd.)

Sample Number	Total Bar Weight (g)	Insulation Length (in.)	Insulation Areal Dimensions* (in.)	Visual Observations
N22	Not Measured	Not Measured	Not Measured	Not Visually Inspected.
G37	83.1	~10	0.555/0.310, 0.545/0.361, 0.562/0.401, 0.584/0.424, 0.549/0.320	Overlapped tape. Overall beige color from Secon-5 binder coating. Very little coating material flaked off. Two wraps of ceramic insulating twine ~1/4 in. from numbered end to tie down insulation.
G38	85.5	~10 ⅛	0.569/0.312, 0.554/0.384, 0.560/0.413, 0.619/0.434, 0.538/0.317	Overlapping tape. Overall beige color from Secon-5 coating. Very little coating material flaked off. Two wraps of ceramic insulating twice ~1/8 in. from numbered end of sample to tie down tape. Sample lumpy.
3A-92	Not Measured	Not Measured	Not Measured	Not Visually Inspected.
4A	Not Measured	Not Measured	Not Measured	Not Visually Inspected.

*Measured from numbered end at ~0.25, 2.5, 5, 7.5, and ~9.75 in. axial locations.

TABLE XII. Temperature Test First and Second Electrical Measurement Results*

Sample Number	Megger at 1000 V (GΩ)		Hipot at 3000 V AC (mA)	
	First Test (Preaging)	Second Test (Postaging)	First Test (Preaging)	Second Test (Postaging)
G17	6.8	>100	0.237	0.187
G18	4.3	N.A.	0.230	N.A.
G19	4.2	N.A.	0.239	N.A.
9	0.320	>100	0.344	0.236
10	0.180	>100	0.365	0.231
11	0.200	>100	0.373	0.223
N20	N.T.	N.T.	N.T.	N.T.
N21	N.T.	N.T.	N.T.	N.T.
N22	N.T.	N.T.	N.T.	N.T.
G37	6.8	75	0.222	0.183
G38	5.8	N.A.	0.220	N.A.
3A-92	N.T.	N.T.	N.T.	N.T.
4A	N.T.	N.T.	N.T.	N.T.

*Obtained before (first electrical measurement) and after (second electrical measurement) the initial oven accelerated aging test.

<u>Key</u>

N.A. = Not aged as per "Test Plan" instructions.
N.T. = Not tested as samples were received initially uncured.

TABLE XIII. Temperature Test First Toshiba Aging Test Data

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp (°C)	Leakage Current (mA)		
					Sample 9	Sample 10	Sample 11
5-03-93	1545	-	110	730	0.39	0.31	0.45
5-03-93	1555	-	250	730	0.86	0.66	0.10
5-03-93	1557	-	510	730	1.74	1.40	1.98
5-03-93	1558	0.00	602	730	2.03	1.63	2.29
5-03-93	1630	0.25	700	730	1.81	1.50	2.00
5-03-93	1700	1.0	700	730	1.77	1.45	1.90
5-04-93	0650	15.0	592	730	1.06	0.95	1.03
5-04-93	1100	19.0	596	730	1.01	0.90	0.96
5-04-93	1615	24.0	608	730	0.95	0.85	0.90
5-05-93	0640	38.5	593	730	0.82	0.75	0.79
5-05-93	1459	44.6	591	730	0.79	0.71	0.75
5-05-93	1630	48.5	600	730	0.79	0.71	0.76
5-06-93	0645	62.7	601	730	0.72	0.66	0.70
5-06-93	1605	72.30	602	730	0.71	0.64	0.69
5-07-93	0700	87.3	597	730	0.67	0.60	0.65
5-07-93	1605	96.0	603	730	0.66	0.60	0.64
5-10-93	0645	156.5	599	730	0.62	0.56	0.61
5-10-93	1600	168.0	605	730	0.64	0.57	0.62
5-11-93	0800	184.0	603	730	0.63	0.56	0.61
5-11-93	1700	193.0	606	730	0.62	0.56	0.61
5-12-93	0800	208.0	605	730	0.62	0.55	0.61
5-12-93	1600	216.0	612	730	0.62	0.55	0.61
5-13-93	0800	231.0	612	730	0.62	0.55	0.61
5-13-93	1600	239.0	626	730	0.63	0.56	0.62
5-14-93	0800	254.0	592	730	0.60	0.53	0.60
5-14-93	1600	262.0	603	730	0.62	0.55	0.61
5-17-93	0700	325.0	597	730	0.58	0.52	0.60

TABLE XIII. (Contd.)

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp (°C)	Leakage Current (mA)		
					Sample 9	Sample 10	Sample 11
5-17-93	1600	336.0	604	730	0.59	0.52	0.61
5-18-93	0700	351.0	598	730	0.57	0.51	0.59
5-18-93	1600	360.0	601	730	0.59	0.52	0.61
5-19-93	0700	375.0	605	730	0.59	0.52	0.63
5-19-93	1600	384.0	604	730	0.58	0.51	0.60
5-20-93	0700	399.0	605	730	0.55	0.51	0.60
5-20-93	1600	408.0	605	730	0.88	0.80	0.60
5-21-93	0700	423.0	599	730	0.57	0.50	0.60
5-21-93	1600	432.0	598	730	0.56	0.49	0.60
5-24-93	0700	495.0	598	730	0.57	0.51	0.60
5-24-93	1300	501.0	606	730	0.54	0.52	0.60

1. <u>Physical Examination</u>

As part of the posttemperature physical examination phase, photographs were taken of each bar sample both just after the temperature test (i.e., Phase 5 in Table X) as well as after the second aging test (i.e., Phase 7 in Table X). Representative photographs of samples after these two phases are presented in Appendix B. A complete physical examination, including a visual examination, sample weighing, and dimensional measurements was made as part of the final examination (i.e., Phase 9 of Table X).

The final examination results for the 13 temperature test bar samples are presented in Table XVI.

TABLE XIV. Temperature Test First General Electric White Mica Aging Test Data

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp (°C)	Leakage Current (mA)	
					Sample G37	Sample G17
5-03-93	1602	-	200	730	0.40	0.12
5-03-93	1605	-	500	730	1.01	0.29
5-03-93	1610	-	750	730	1.52	0.41
5-03-93	1612	-	1000	730	2.10	0.56
5-03-94	1614	-	1250	730	2.74	0.70
5-03-93	1617	0.0	1500	730	3.46	0.85
5-03-93	1630	0.25	1500	730	3.77	0.82
5-03-93	1700	0.75	1500	730	4.04	0.76
5-04-93	0645	14.5	1470	730	6.69	0.68
5-04-93	1100	19.0	1470	730	4.04	0.69
5-04-93	1615	24.0	1476	730	7.48	0.72
5-05-93	0640	38.5	1463	730	7.93	0.73
5-05-93	1250	44.6	1459	730	8.09	0.74
5-05-93	1630	48.0	1509	730	8.52	0.80
5-06-93	0650	62.7	1505	730	8.78	0.82
5-06-93	1610	72.3	1502	730	8.92	0.85
5-07-93	0700	87.3	1501	730	8.97	----
5-07-93	1610	96.0	1505	730	9.11	----

TABLE XIV. (Contd.)

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp (°C)	Leakage Current (mA)	
					Sample G37	Sample G17
5-10-93	0645	156.5	1502	730	9.39	0.86
5-10-93	1615	168.0	1505	730	9.42	0.87
5-11-93	0800	184.0	1505	730	9.47	0.89
5-11-93	1700	193.0	1503	730	9.60	0.88
5-12-93	0800	208.0	1506	730	9.54	0.91
5-12-93	1600	216.0	1534	730	9.49	0.91
5-13-93	0800	231.0	1498**	730	9.38	0.97
5-13-93	1600	239.0	1532	730	9.66	0.99
5-14-93	0800	254.0	1502	730	9.35	0.95
5-14-93	1600	262.0	1502	730	9.59	0.95
5-17-93	0700	325.0	1505	730	9.46	0.94
5-17-93	1605	336.0	1503	730	9.41	0.95
5-18-93	0700	351.0	1502	730	9.32	0.94

TABLE XV. Temperature Test First General Electric Nextel Sample Aging Test Data

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp (°C)	Leakage Current (mA)	
					Sample 3A-92	Sample N20
8-28-93	1030	-	250	730	0.03	0.05
8-28-93	1052	-	495	730	0.04	0.08
8-28-93	1055	-	790	730	0.06	0.08
8-28-93	1056	-	1000	730	0.07	0.15
8-28-93	1057	-	1278	730	0.09	0.20
8-28-93	1059	0.0	1500	730	0.11	0.23
8-28-93	1300	2.0	1500	730	0.11	0.20
8-28-94	1540	4.0	1525	730	0.11	0.18
8-30-93	0905	46.0	1490	730	0.12	0.13

TABLE XVI. Temperature Test Final Examinations

Sample Number	Total Bar Weight (g)	Insulation Length (in.)	Insulation Areal Dimensions* (in.)	Visual Observations
G17	81.9	~10-1/8	0.526/0.319, 0.550/0.344, 0.567/0.358, 0.580/0.366, 0.544/0.360	Outer wrap split in several places. Brownish to dark brown color with silvery patches. Insulating twine still on.
G18	90.2	~9-7/8	0.593/0.408, 0.565/0.392, 0.547/0.387, 0.556/0.397, 0.523/0.318	Overall appearance brown. Some darkening at unnumbered end.
G19	90.0	~9-7/8	0.610/0.390, 0.570/0.407, 0.552/0.405, 0.538/0.388, 0.528/0.319	Overall appearance tan colored surface; some shiny spots showing through. One edge appears to have a black crystalline deposit especially at unnumbered end.
9	81.9	~10.0	0.553/0.291, 0.547/0.250, 0.532/0.258, 0.502/0.262, 0.471/0.242	Appearance seems little changed from original except that there is some darkening at the unnumbered end. Cu bar is also very badly oxidized at that location.
10	81.6	~10.0	0.507/0.295, 0.518/0.271, 0.522/0.278, 0.535/0.288, 0.461/0.288	Appearance little changed from original except for the darkening at unnumbered end. Considerable oxidation of Cu at unnumbered end.
11	84.0	~10-1/8	0.567/0.334, 0.523/0.284, 0.528/0.283, 0.502/0.267, 0.479/0.259	Weight includes broken screw. Appearance little changed from original except for darkening at end with broken screw.
N20	82.2	~10-1/8	0.443/0.208, 0.486/0.281, 0.498/0.280, 0.495/0.287, 0.483/0.253	White woven appearance with some discolorations at numbered end. Color ranged from beige to yellowish brown.
N21	81.2	~10.0	0.451/0.258, 0.493/0.271, 0.484/0.274, 0.490/0.278, 0.486/0.258	Appearance the same as sample N20.

TABLE XVI. (Contd.)

Sample Number	Total Bar Weight (g)	Insulation Length (in.)	Insulation Areal Dimensions* (in.)	Visual Observations
N22	82.2	~10.0	0.466/0.217, 0.494/0.281, 0.489/0.280, 0.481/0.279, 0.515/0.282	Appearance the same as samples N20 and N21.
G37	85.2	~9-7/8	0.521/0.315, 0.534/0.358, 0.550/0.368, 0.549/0.366, 0.558/0.382	Very bright and shiny appearance. Most all of original beige color gone. Exposed conductor bar very thin and fragile.
G38	84.2	~10.0	0.595/0.313, 0.556/0.388, 0.559/0.393, 0.596/0.428, 0.543/0.326	Color appeared paler than original color. Little change in overall appearance. Some darkening at unnumbered end.
3A-92	80.6	~9-7/8	0.452/0.195, 0.482/0.293, 0.488/0.306, 0.425/0.295, 0.452,0.186	Flaked white, very silvery appearance where white has flaked off. Darkened at numbered end.
4A	80.7	~10.0	0.427/0.176, 0.479/0.286, 0.482/0.297, 0.482/0.293, 0.462/0.253	Appearance same as sample 3A except no darkening at end.

* Measured from numbered end at ~0.25, 2.5, 5, 7.5, and ~9.75 in. axial locations.

2. Electrical Testing

The posttemperature electrical testing was performed after the temperature test (i.e., Phase 6 in Table X) and after the second aging test (i.e., Phase 8 of Table X). The electrical testing again consisted of the standard electrical insulation Megger and Hipot tests. Sample preparation and measurement procedures were also identical to those described previously (see Sect. III).

The posttemperature test electrical measurement results are presented in Tables XVII and XVIII. Table XVII contains the electrical measurement results for the third electrical measurements performed on the temperature test samples (i.e., Phase 6 in Table 10). In Table XVIII, the fourth Megger and Hipot electrical measurement results are presented (i.e., Phase 8 in Table X).

3. Accelerated Age Testing

The second aging test was conducted in this posttemperature test program phase. It was performed after the temperature test itself and was Phase 7 of the temperature test program (see Table X). Temperature and voltage conditions in the ovens that were impressed on the bar samples were the same as during the first temperature test oven aging test conducted during the pretemperature testing program.

The leakage current results obtained during the second accelerated aging test for the Toshiba samples are presented in Table XIX. As was the case for the previous Toshiba accelerated aging tests, the oven temperature was set at ~730°C with the voltage across the bars being ~600 V. The leakage current results for the GE insulation bar samples during the second accelerated aging test are tabulated in Table XX. Again, as was the case for the previous GE aging oven tests, a temperature of ~730°C was specified with the applied voltage being ~1500 V.

TABLE XVII. Temperature Test Third Electrical Measurement Results*

Sample Number	Megger at 1000 V (GΩ)	Hipot at 3000 V AC (mA)
G17	>100	0.195
G18	>100	0.186
G19	>100	0.181
9	>100	0.218
10	>100	0.228
11	>100	0.217
N20	>100	0.190
N21	>100	0.201
N22	>100	0.202
G37	>100	0.182
G38	>100	0.183
3A-92	>100	0.192
4A	>100	0.199

*Obtained after the oven test in Canister 4 in a nitrogen gas atmosphere at EBR-II temperatures.

TABLE XVIII. Temperature Test Fourth Electrical Measurement Results*

Sample Number	Megger at 1000 V (GΩ)	Hipot at 3000 V AC (mA)
G17	>100	0.189
9	>100	0.229
10	>100	0.221
11	>100	0.208
N20	>100	0.185
G37	>100	0.184
3A-92	>100	0.189

*Obtained after second accelerated aging oven test.

TABLE XIX. Temperature Test Second Toshiba Aging Test Data

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp °C	Leakage Current (mA)		
					Sample 9	Sample 10	Sample 11
3-09-94	0900	-	191	729	0.04	0.03	0.04
3-09-94	0900	-	475	729	0.08	0.07	0.09
3-09-94	0900	0.0	595	729	0.10	0.08	0.11
3-10-94	0905	24.0	607	730	0.10	0.07	0.10
3-11-94	0900	48.0	607	729	0.10	0.07	0.10
3-14-94	0900	120.0	604	729	0.09	0.10	0.10
3-16-94	0900	168.0	603	731	0.10	0.07	0.11
3-17-94	0910	192.0	593	731	0.10	0.07	0.11
3-18-94	0900	216.0	588	729	0.12	0.09	0.13
3-21-94	0900	288.0	624	729	0.12	0.10	0.13
3-22-94	0900	312.0	585	729	0.12	0.09	0.13
3-23-94	0900	336.0	606	730	0.13	0.09	0.13
3-24-94	0900	360.0	583	730	0.11	0.09	0.12
3-25-94	0900	384.0	605	730	0.13	0.10	0.13
3-28-94	0900	456.0	581	731	0.12	0.09	0.13
3-29-94	0900	480.0	593	731	0.13	0.10	0.14
3-30-94	0900	504.0	587	731	0.13	0.10	0.14

TABLE XX. Temperature Test Second General Electric Aging Test Data

Date	Time	Elapsed Time (h)	Applied Voltage (V)	Temp °C	Leakage Current (mA)			
					Sample G37	Sample G17	Sample 3A-92	Sample N20
1-24-94	0900	-	237	733	0.02	0.13	0.01	0.04
1-24-94	0900	-	509	733	0.04	0.26	0.03	0.08
1-24-94	0900	-	756	733	0.06	0.38	0.04	0.12
1-24-94	0900	-	1004	733	0.07	0.46	0.04	0.16
1-24-94	0900	-	1324	733	0.10	0.70	0.70	0.22
1-24-94	0900	0.0	1497	733	0.10	0.75	0.07	0.25
1-25-94	1500	30.0	1524	736	0.07	0.81	0.08	0.22
1-26-94	0900	48.0	1504	734	0.07	0.78	0.08	0.20
1-27-94	0900	72.0	1506	735	0.07	0.76	0.09	0.21
1-28-94	0910	96.0	1489	735	0.06	0.73	0.09	0.19
1-31-94	0900	168.0	1425	735	0.07	0.73	0.10	0.19
2-01-94	0900	192.0	1470	735	0.06	0.72	0.10	0.18
2-02-94	0900	216.0	1508	735	0.06	0.73	0.10	0.19
2-03-94	0830	239.5	1508	735	0.06	0.75	0.10	0.19
2-04-94	0900	264.0	1497	735	0.05	0.75	0.10	0.20
2-07-94	0910	336.0	1492	734	0.06	0.75	0.11	0.20
2-08-94	0900	360.0	1486	734	0.05	0.75	0.11	0.21
2-13-94	1900	490.0	1504	733	0.05	0.80	0.12	0.21
2-14-94	0930	504.0	1485	734	0.05	0.79	0.12	0.22

VII. SUMMARY OF POSTIRRADIATION TESTS

The irradiation test phase and postirradiation examination and test phase of the EM pump insulation irradiation test program is described in this report. These tests constitute the second and third parts of a three phase program which includes the irradiation of 39 insulation bar samples in the J2 thimble of EBR-II. The first part of this comprehensive evaluation program consisted of the preirradiation examinations and tests which essentially duplicated the postirradiation tests on selected samples, as described previously in Ref. 1. A comparison of the preirradiation results with the postirradiation results will help establish the suitability of the selected EM pump insulation material for application in the ALMR.

The centerpiece of this pump insulation performance test and evaluation program was the irradiation of 39 selected insulation bar samples in the J2 thimble of EBR-II. These samples representing a cross section of insulation materials and binders were irradiated in three nitrogen gas-filled canisters. The EBR-II irradiation which began in Run No. 165A reached the temperature stabilized sample condition on August 1, 1993. The test was conducted in the J2 thimble of the Nuclear Instrument Test Facility (NITF) which is located outside the core in the radial shield region. The irradiation test was designated the NI-10 test; the samples experienced a ~92.5 day irradiation cycle. The temperatures that the samples were subjected to were measured with two thermocouples located on the outer surface of each canister.

Measured temperatures were ~830°F (444°C) on the upper canister, ~1000°F (538°C) on the middle canister, and ~1140°F (616°C) on the lower canister, which was located closest to the core. The calculated neutron fluences that the insulation samples experienced were within the range that was desired.

A fourth NI-10 test canister, containing EM insulation bar samples similar to those under irradiation was filled with nitrogen, sealed, and placed in an aging oven at ANL-East. This "temperature test" subjected the samples to the temperature history experienced by the hottest canister undergoing irradiation (lower canister). The oven was therefore set to ~1140°F (616°C) with its temperature history mimicking the ~92.5 day irradiation cycle.

In the initial preirradiation and final postirradiation examinations and tests the focus was on evaluating the physical and electrical insulation characteristics of three types of insulation bar samples. Two of these insulation types, white mica and amber mica, were fabricated by the General Electric Co. using Secon-5 potting compound as a binder. The third insulation material evaluated in this study was splitting mica with silicon binder which was fabricated by the Toshiba Corp. All of the approximately 60 insulation bar samples tested in this program consisted of a small copper bar (~10 in. long by ~0.5 in. x ~0.25 in. cross section) and were wrapped with various combinations of insulation tape and binder. The weight of these samples was approximately 85 g. The physical examinations that were performed on these samples included a visual inspection, a weighing, dimensional checks, and photographs of each sample. The electrical tests consisted of a direct current insulation resistance test (i.e., Megger test) and an alternating current leakage test (i.e., Hipot test). These electrical tests were performed on the samples both before and after an accelerated aging test.

The accelerated aging tests were conducted in the ovens at ANL-East with the radioactive samples aged in an oven shipped from ANL-East to ANL-West. The sample temperature was ~1350°F with the applied voltage being either 600 V AC (splitting mica samples) or 1500 V AC (white and amber mica samples). These aging tests were scheduled for ~3 weeks duration. However, the poor electrical performance observed for the white mica samples, as measured by the leakage current, dictated that the aging test for the white and amber samples be terminated after ~2 weeks duration. Typical leakage currents for the white mica insulation bars during the aging test were approximately an order of magnitude higher (~10 mA) than the amber and splitting mica (~1 mA).

Based on the relatively poor electrical performance of the white mica as determined in the initial age test, a development program was initiated at GE to find a substitute material. Accelerated age tests were performed at ANL-East on replacement insulation wrapping material which included ceramic tape (i.e., Nextel tape), combinations of amber and ceramic tape, and other binder materials (i.e., boron nitride). After several failures, a ceramic tape/boron nitride insulation system performed satisfactorily in a ~2 week age test.

ACKNOWLEDGMENTS

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1. W. A. Bezella et al., "Electromagnetic Pump Insulation Preirradiation Test Report," Argonne National Laboratory Report, ANL-IFR-229 (May 1994).

2. J. M. Collett, "Insulation Irradiation Testing Requirements," General Electric Report, 23A3915, Revision C (March 1993).

3. J. M. Collett, "NI-10, EM Pump Insulation Materials Irradiation Data Package-Part 1: "Experiment Description," General Electric Report, A1-109-93094, Revision C (June 28, 1993).

APPENDIX A

NEUTRON FLUX AND ACTIVITY ESTIMATES

A. Neutron Flux Estimate at Bar Samples

The neutron flux at the center of the bar sample locations in the J2 thimble of the EBR-II Reactor is predicted using the TWODANT transport theory code. The S^8 discrete ordinates approximation and 30-group cross-section set were used. The group structure is fine enough to track the epithermal flux well. There is one thermal group, whose cross sections were obtained from the THERMOS code. Cross sections for the core and blanket are based on ENDF/B Version 5.2 data, but cross sections for regions beyond there are based on Version 1 data.

The reactor was modeled with RZ geometry. This precluded modeling azimuthal asymmetries, including explicit representation of the J2 thimble. It should be adequate to use the flux in the outer blanket region at the J2 thimble location. Materials present in the aximuthal sector encompassing the J2 thimble, rather than radially averaged compositions, were used. This approximation should give a reasonable representation of the flux at the J2 thimble.

There are three sample canisters stacked one above the other in the J2 thimble. Each sample is a rod about 11 in. long and each canister contains 13 samples arranged in ~3 in. diameter circular pattern. The axial center of the bottom canister is at the core axial midplane. The canister center is 26 in. apart along the axis of the J2 thimble. Note, however, that the J2 thimble axis is tilted 10.863° away from vertical, with the top being radially further out than the bottom. This implies that the samples get further from the core (deeper into the outer shield), the further up the thimble they are.

The neutron flux has been edited at three locations, the centers of the bottom, middle, and top canisters. These three spectra are listed in Table A1. At the bottom of the table are shown the fast flux (groups 1 through 9,

TABLE A1. Neutron Spectrum at Center of Each Canister

Group	E_{max} (eV)	Bottom	Middle	Top
1	1.00E+07	4.40E+07	5.92E+06	4.62E+05
2	6.06E+06	1.78E+08	2.11E+07	1.68E+06
3	3.68E+06	5.21E+08	5.35E+07	4.60E+06
4	2.23E+06	1.61E+09	1.74E+08	1.58E+07
5	1.35E+06	3.10E+09	2.95E+08	2.58E+07
6	8.21E+05	4.57E+09	3.84E+08	3.14E+07
7	4.98E+05	6.55E+09	4.68E+08	3.78E+07
8	3.02E+05	9.34E+09	5.63E+08	4.57E+07
9	1.83E+05	1.21E+10	6.79E+08	5.49E+07
10	1.11E+05	1.59E+10	7.78E+08	6.62E+07
11	6.74E+04	1.99E+10	9.33E+08	7.92E+07
12	4.09E+04	2.46E+10	1.13E+09	9.42E+07
13	2.48E+04	3.31E+10	1.33E+09	1.12E+08
14	1.50E+04	3.78E+10	1.70E+09	1.40E+08
15	9.12E+03	4.32E+10	1.88E+09	1.57E+08
16	5.53E+03	5.02E+10	1.92E+09	1.66E+08
17	3.36E+03	4.40E+10	1.85E+09	1.58E+08
18	2.04E+03	6.87E+10	2.66E+09	2.28E+08
19	1.23E+03	7.11E+10	3.26E+09	2.70E+08
20	7.48E+02	7.44E+10	3.81E+09	3.18E+08
21	4.54E+02	7.79E+10	4.45E+09	3.75E+08
22	2.75E+02	8.19E+10	5.17E+09	4.33E+08
23	1.67E+02	8.58E+10	5.91E+09	4.96E+08
24	1.01E+02	8.95E+10	6.62E+09	5.72E+08
25	6.14E+01	9.27E+10	7.36E+09	6.54E+08
26	3.73E+01	1.95E+11	1.78E+10	1.71E+09
27	2.26E+01	1.98E+11	2.09E+10	2.13E+09
28	1.37E+01	1.94E+11	2.36E+10	2.52E+09
29	5.04E+00	1.83E+11	2.55E+10	2.92E+09
30	4.14E-01	6.60E+11	1.48E+11	2.38E+10
Fast		3.80E+10	2.64E+09	2.18E+08
Total		2.38E+12	2.89E+11	3.76E+10

The flux is normalized to full reactor power, 62.5 MWt.

i.e., above 0.1 MeV) and the total flux. In all cases, the flux is normalized to yield a total reactor power of 62.5 MWt, i.e., full power. The predicted total flux is 2.38×10^{12} in the bottom canister, 2.89×10^{11} in the middle canister, and $3.76\ 10^{10}$ in the top canister.

B. Activity of General Electric Bar Samples

Measurements were made to determine the radioactivity level of the GE irradiated bar samples just prior to subjecting them to their postirradiation tests and examinations. These health physics measurements were required to aid in minimizing the doses received by the technicians conducting the posttest examinations.

Tables A2, A3, and A4 beta and gamma activation levels, taken at the bar surface, are reported for Canisters 1, 2, and 3, respectively. As Table A2 indicates, no activity was measured for the Canister 1 samples located in the J2 assembly carrier farthest from the reactor core. The high activation levels of the bar samples in Canister 3 closest to the reactor core, are evident in Table A4.

Also provided in Tables A2 and A3 are the type of wrapping provided for the posttest examinations. The age testing disposition (yes or no) for each sample is also indicated in these tables.

Surface contaminations measurements were also made for two of the bar samples in Canister 2. These two high-activity-level bar samples were Samples G7 and G8. For Sample G7 a surface smear of 8,000 dpm was recorded with Sample G8 indicating a surface smear count of 30,000 dpm.

TABLE A2. Activity of General Electric Samples in Canister 1

Storage Tube	Sample ID No.	Activation Beta-Gamma	Activation Gamma	Type of Wrap	Age Test
1	G1	-	-	Al-SS-Al	Yes
2	N10	-	-	Al-SS-Al	Yes
3	G22	-	-	Al-SS-Al	Yes
5	G2	-	-	Al-SS-Al	Yes
7	G3	-	-	Al-SS-Al	Yes
8	N11	-	-	Al-SS-Al	Yes
9	G21	-	-	Al-SS-Al	Yes
10	G4	-	-	Al only	No
11	G5	-	-	Al only	No
13	N12	-	-	Al only	No

TABLE A3. Activity of General Electric Samples in Canister 2

Storage Tube	Sample ID No.	Activation Beta-Gamma	Activation Gamma	Type of Wrap	Age Test
1	G6	200 mR/h	100 mR/h	SS only	Yes
2	N13	80	60	SS only	Yes
3	N14	Background *	-	SS only	Yes
4	3A	400	200	Al only	No
5	G7	450	220	SS only	Yes
6	G26	100	60	SS only	Yes
7	G8	500	250	SS only	Yes
8	N15	Background *	-	SS only	Yes
9	N16	Background *	-	Al only	No
10	G9	380	200	Al only	No
11	G10	400	200	Al only	No
12	G11	400	200	Al only	No
13	2A	400	200	SS only	Yes

*Background is 60.

TABLE A4. Activity of General Electric Samples in Canister 3

Storage Tube	Sample ID No.	Activation Beta-Gamma	Activation Gamma	Type of Wrap	Age Test
1	G12	1.4 R/h	600 mR/h	Al only	No
2	N17	600	600	SS only	Yes
3	G33	600	500	SS only	Yes
5	G13	1.6 R/h	1 R/h	Al only	No
7	G14	1.5 R/h	1 R/h	SS only	Yes
8	N18	500	500	Al only	No
9	G32	600	500	Al only	No
10	G15	1.2 R/h	700	Al only	No
11	G16	1.2 R/h	700	Al only	No
13	N19	500	500	Al only	No

APPENDIX B

REPRESENTATIVE PHOTOGRAPHS

TABLE B1. General Electric and Toshiba Bar Sample Conditions After Irradiation

Sample	Good	Poor	Comments
General Electric Samples			
N10	X		Brown - Insulation looks good.
N11	X		Brown - Insulation looks good, flaked a little.
N12	X		Brown - Insulation looks good, flaked a little.
N13	X		White - Unraveled on hole end, slightly discolored.
N14		X	White - Unraveled on ID end, slightly discolored.
N15		X	White - Unraveled on both ends, slightly discolored.
N16		X	White - Unraveled on both ends, slightly discolored.
N17		X	White - Unraveled on ID end, otherwise, looks good.
N18		X	White - Unraveled on both ends, otherwise, good.
N19		X	White - Unraveled on both ends, green on one edge.
2A	X		White - Insulation good, discolored a little.
3A		X	White - Insulation unwrapped on ID end. (one turn)
G1		X	White - Slightly unraveled and discolored on ends.
G2	X		Brown - unraveled on ID end.
G3	X		White - Slightly unraveled on hole end.
G4	X		Brown - Insulation looks good, flaked a little.
G5	X		White - Slightly unraveled and discolored on ends.
G6	X		Brown - Insulation good, discolored a little.
G7	X		Brown - Insulation good, discolored a little.
G8	X		Brown - Insulation good, discolored a little.
G9	X		Brown - Insulation good, discolored a little.
G10	X		Brown - Insulation good, discolored a little.
G11	X		Brown - Insulation good, discolored a little.
G12	X		Brown - Insulation good, discolored a little.

TABLE B1. (Contd.)

Sample	Good	Poor	Comments
General Electric Samples			
G13	X		Brown - Insulation good, green color on one edge.
G14	X		Brown - Insulation good, discolored a little.
G15	X		Brown - Insulation good, green and black color on one edge.
G16	X		Brown - Insulation very good condition
G21	X		Brown - Insulation looks good, flaked a little.
G22	X		Brown - Insulation looks good.
G26	X		Brown - Unraveled on ID end, slightly discolored.
G32	X		Brown - Insulation looks good discolored.
G33	X		Brown - Insulation looks good.
Toshiba Samples			
1	X		Appears normal
2	X		Appears normal
3	X		Appears normal
4	X		Cu appears oxidized. More green color on insulation.
5	X		Cu appears oxidized. More green color on insulation.
6	X		Cu appears oxidized on one end. Some green color.

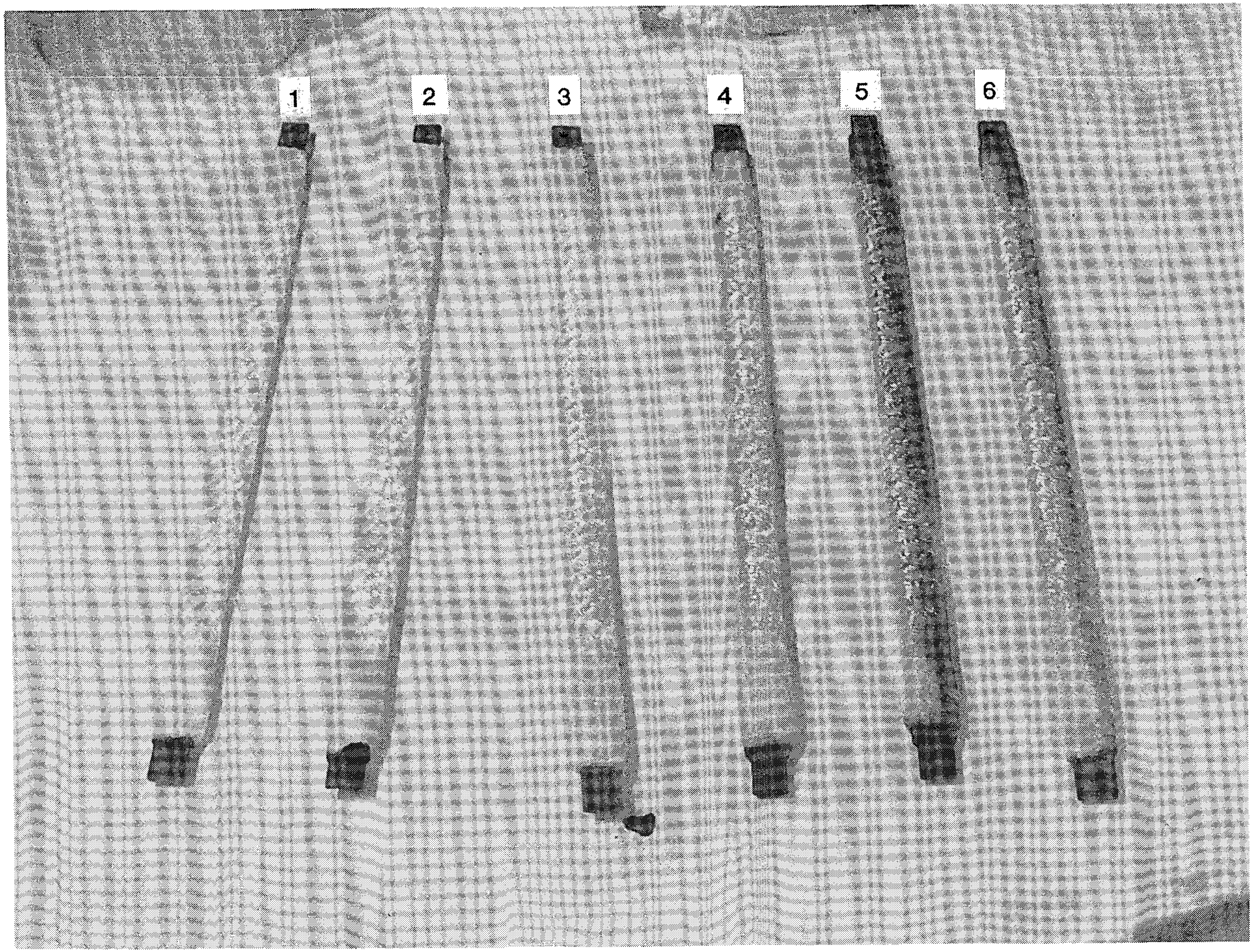


Fig. B1. Toshiba Bar Samples After Irradiation

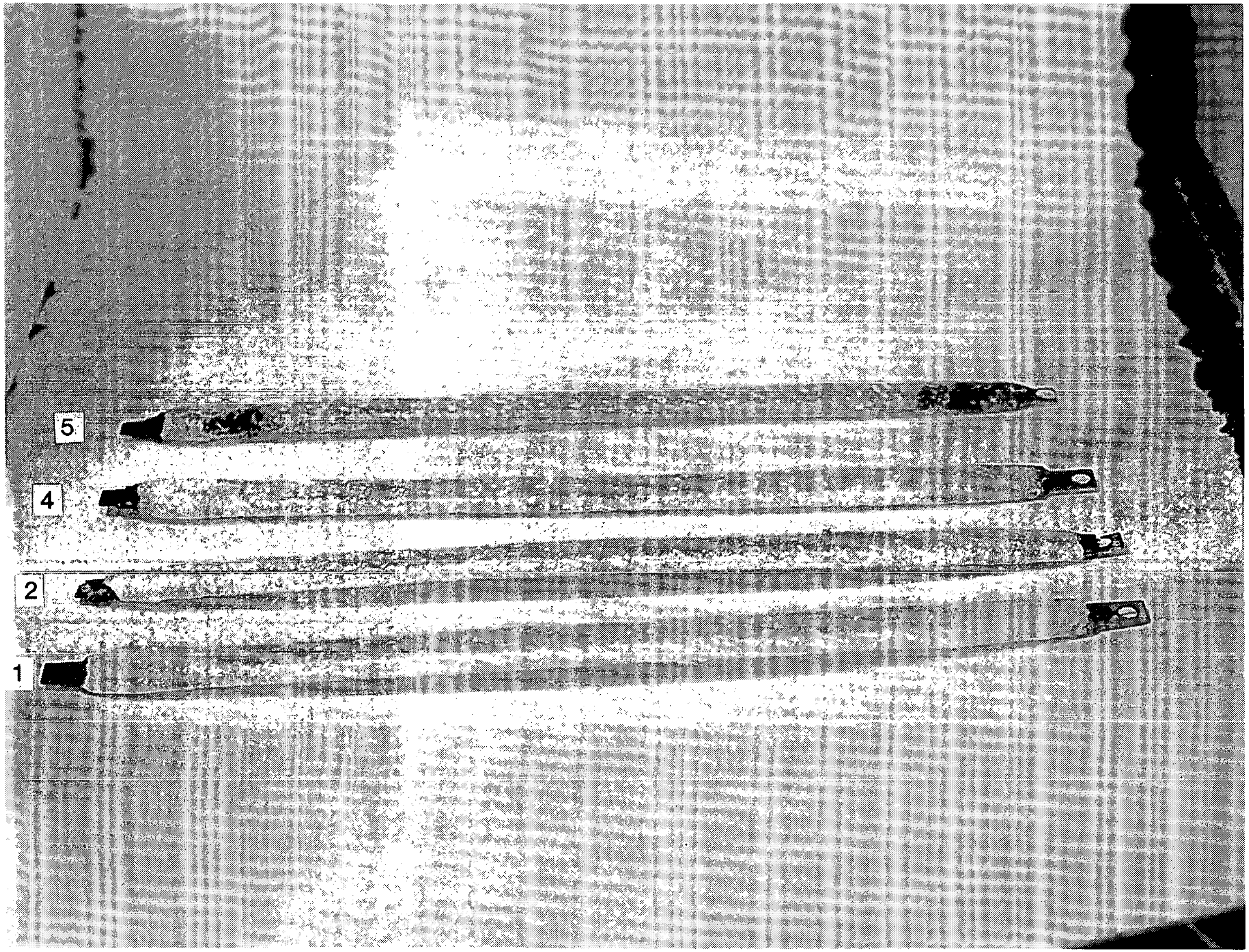


Fig. B2. Toshiba Bar Samples After Aging Tests

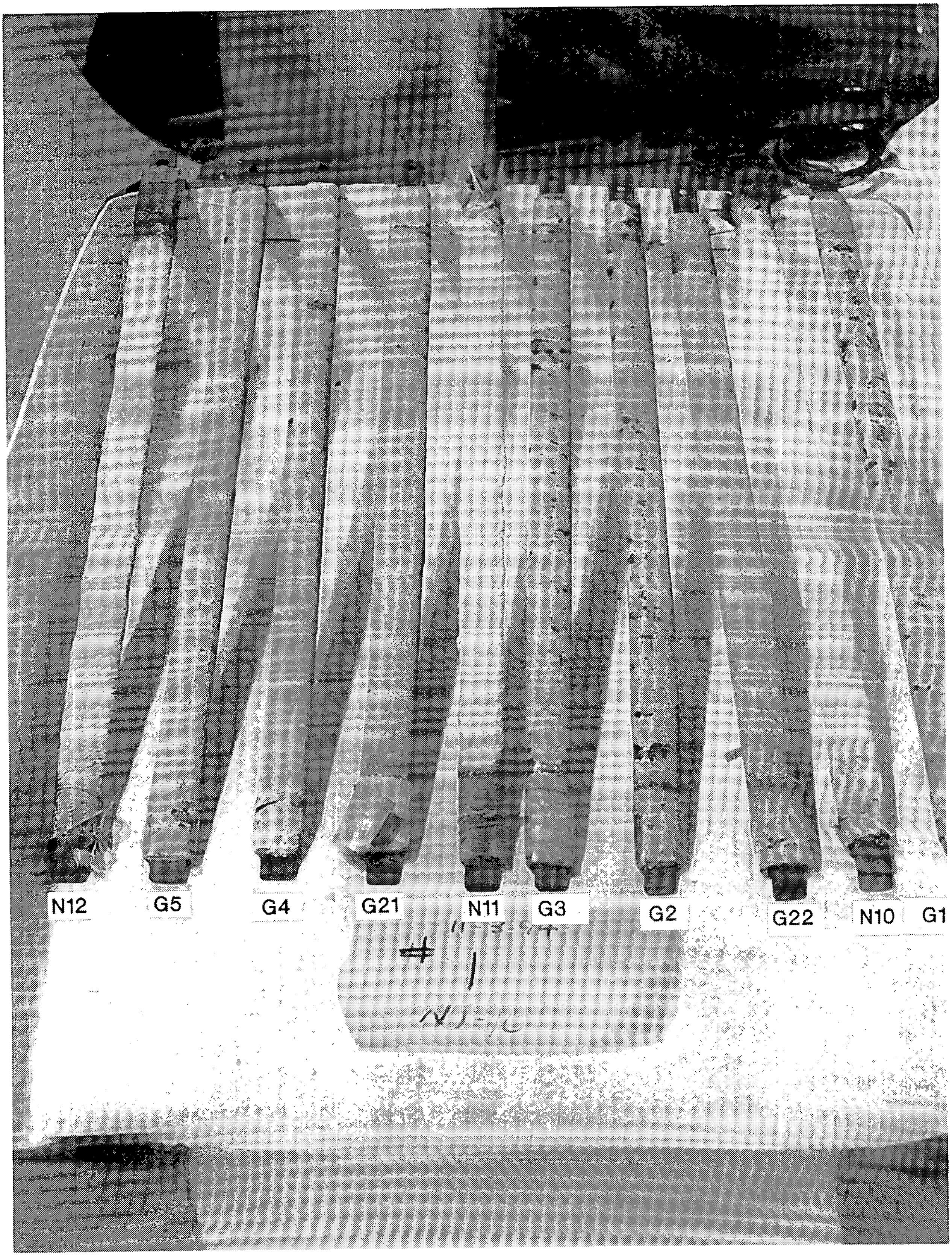


Fig. B3. General Electric Samples From Canister 1 After Irradiation

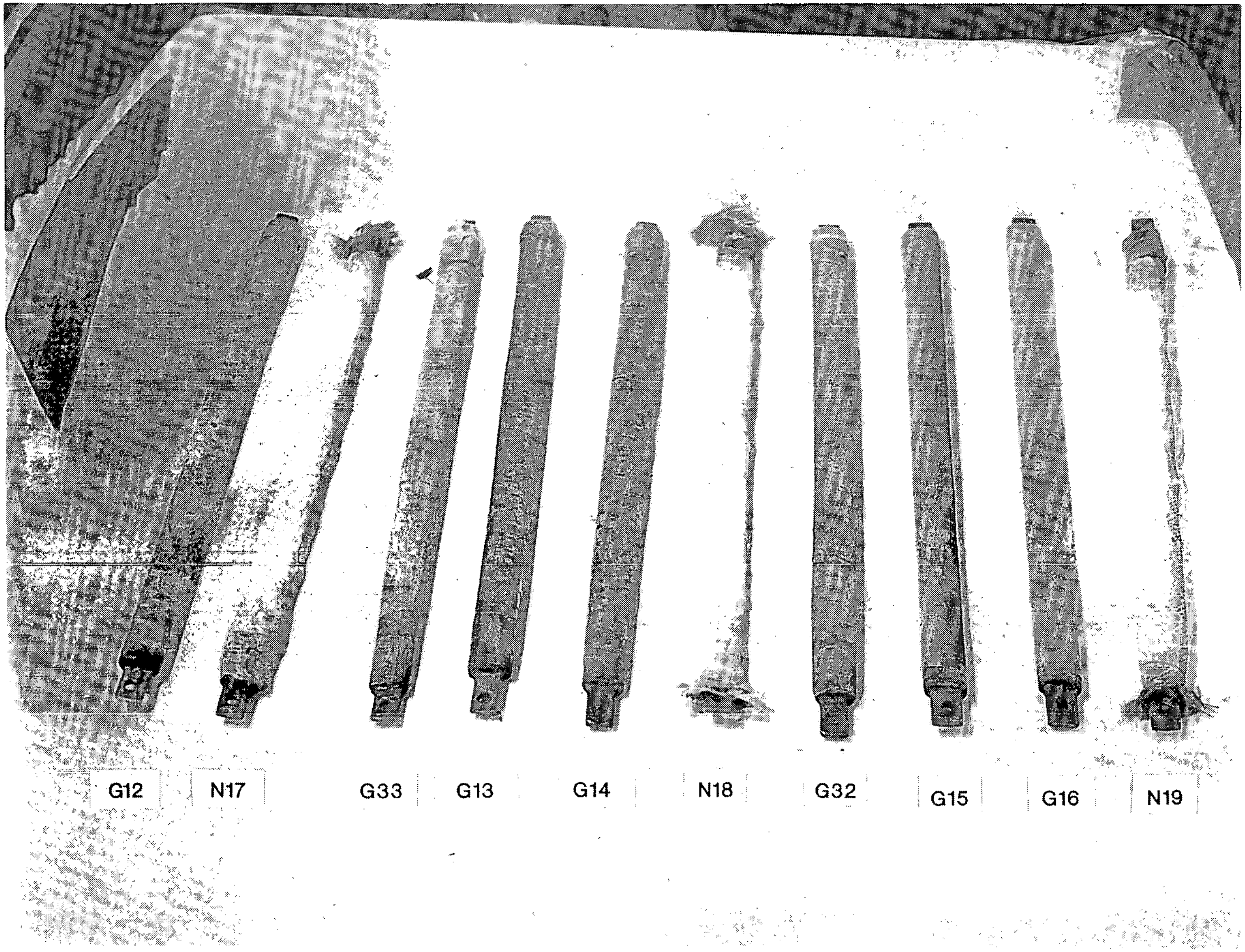
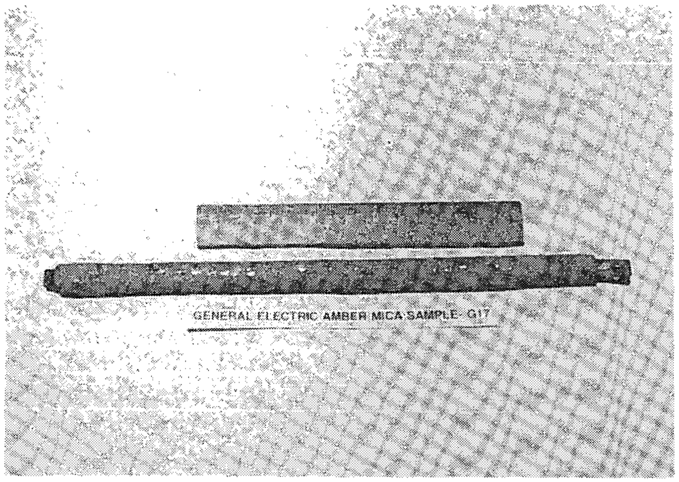
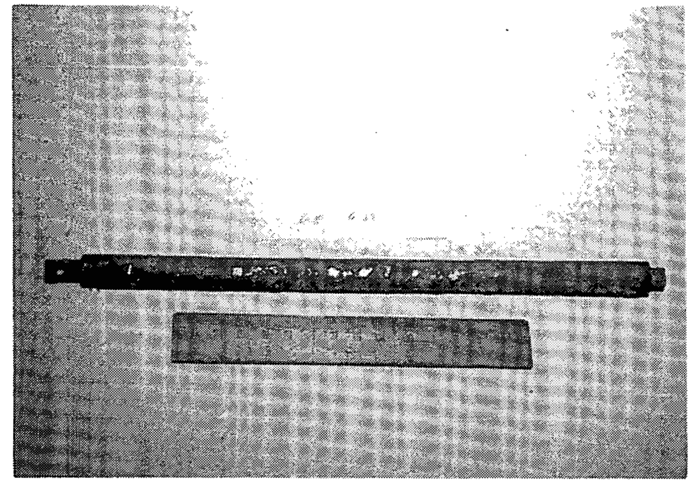


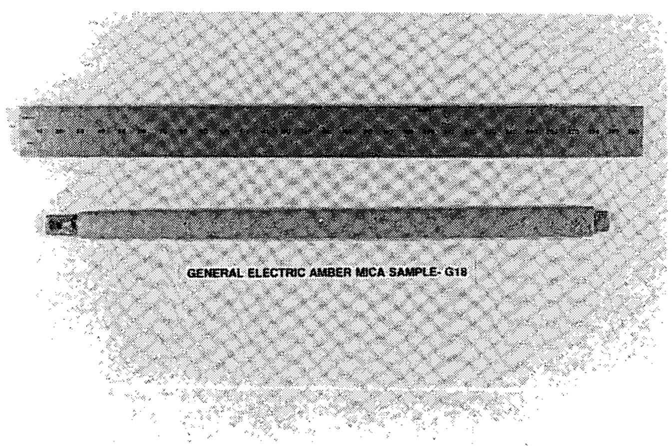
Fig. B4. General Electric Samples From Canister 3 After Irradiation



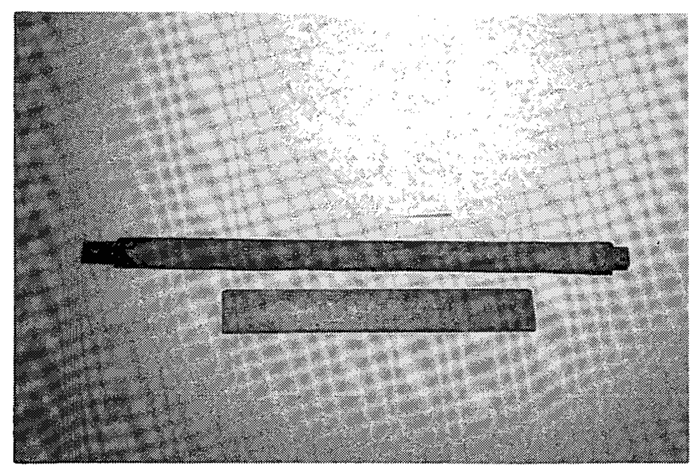
a. Sample G17 Before (ANL Neg. No. 15263K, Frame 10A)



b. Sample G17 After (ANL Neg. No. 16375K, Frame 7A)

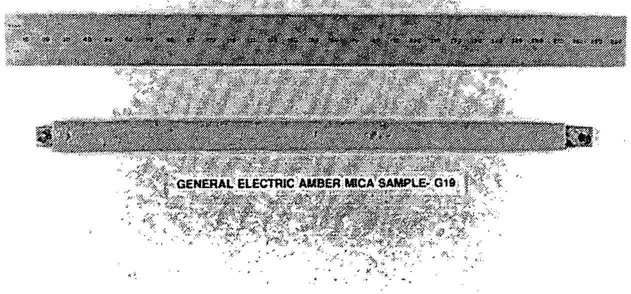


c. Sample G18 Before (ANL Neg. No. 15047, Frame 24)

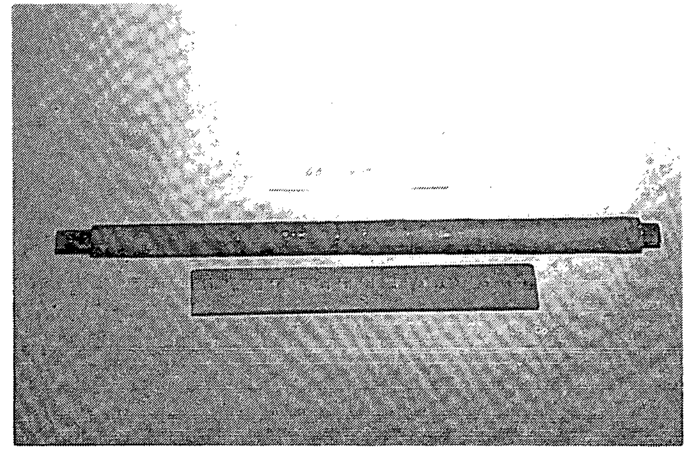


d. Sample G18 After (ANL Neg. No. 16375K, Frame 8A)

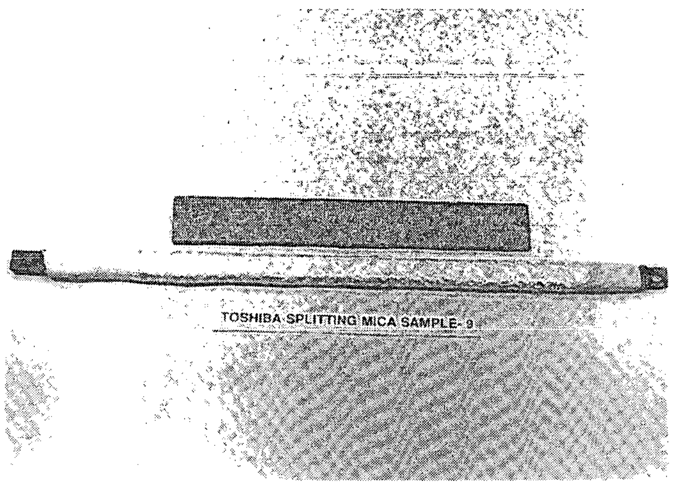
Fig. B5. General Electric Samples After Aging Tests



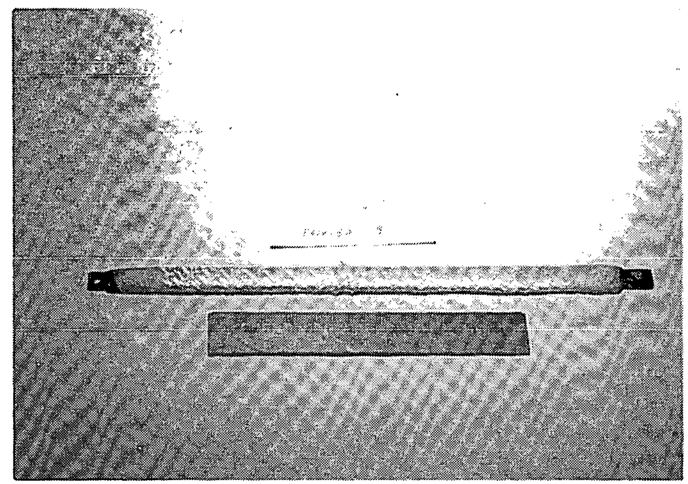
e. Sample G19 Before (ANL Neg. No. 15046, Frame 12)



f. Sample G19 After (ANL Neg. No. 16375K, Frame 9A)

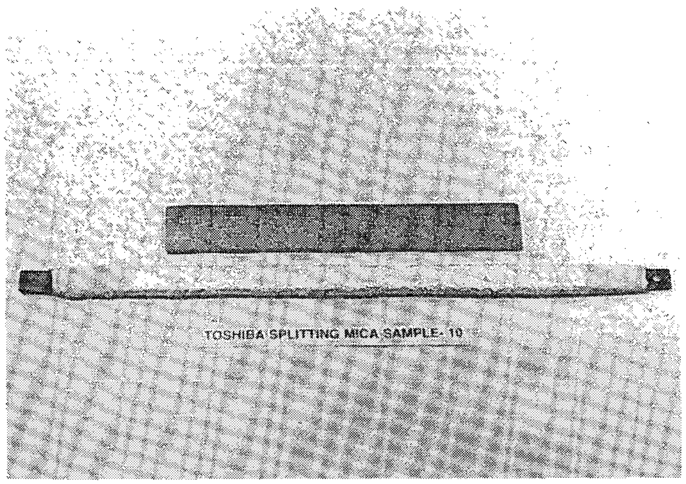


g. Sample Toshiba 9 Before (ANL Neg. No. 15314K, Frame 14A)

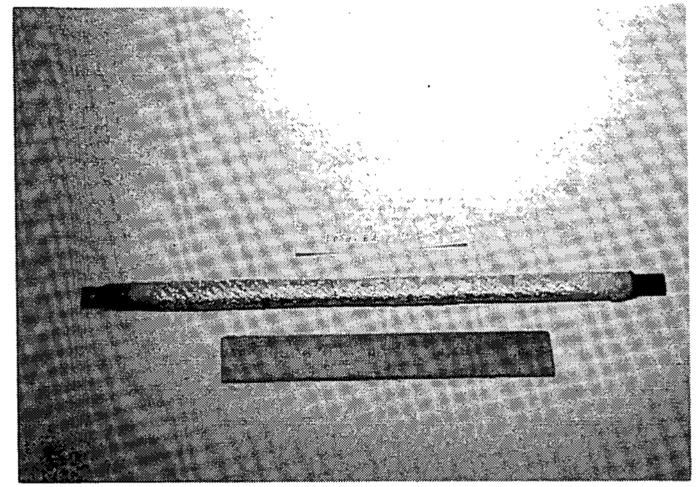


h. Sample Toshiba 9 After (ANL Neg. No. 16375K, Frame 17A)

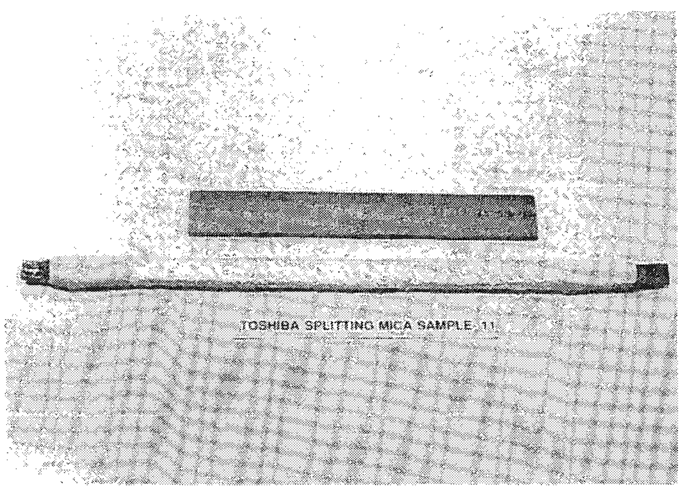
Fig. B5. (Contd.)



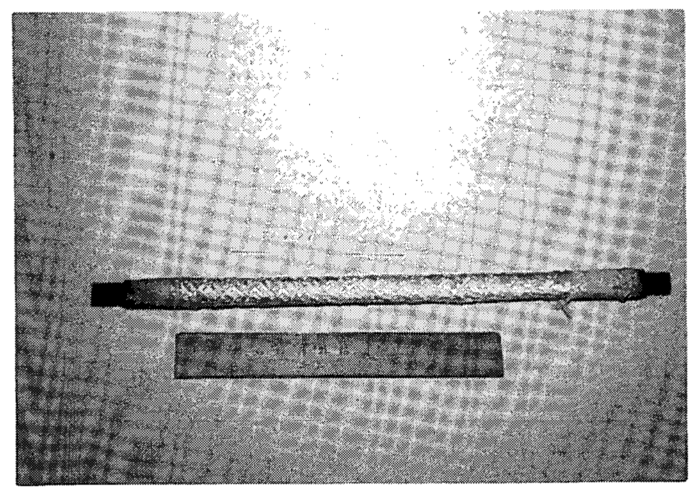
i. Sample Toshiba 10 Before (ANL Neg. No. 15314K, Frame 16A)



j. Sample Toshiba 10 After (ANL Neg. No. 16375K, Frame 18A)

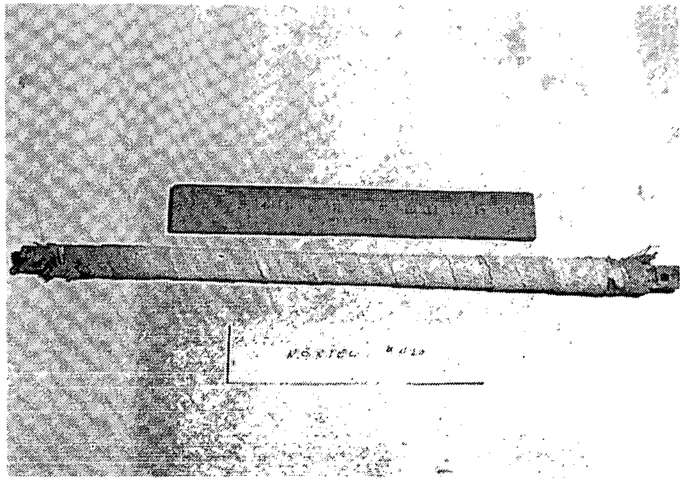


k. Sample Toshiba 11 Before (ANL Neg. No. 15314K, Frame 17A)

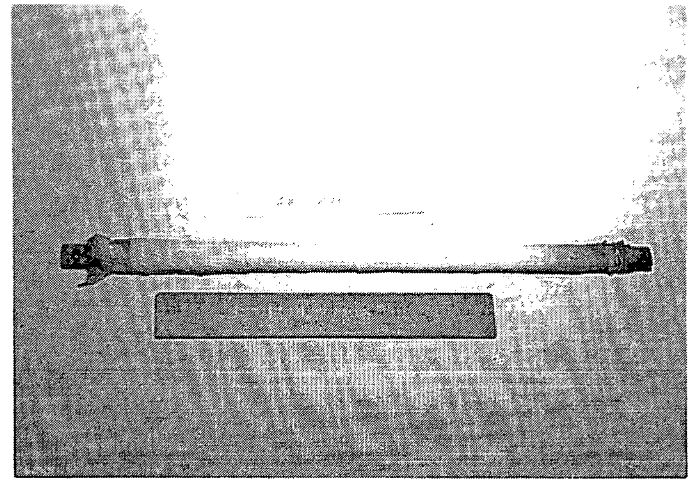


l. Sample Toshiba 11 After (ANL Neg. No. 16375K, Frame 19A)

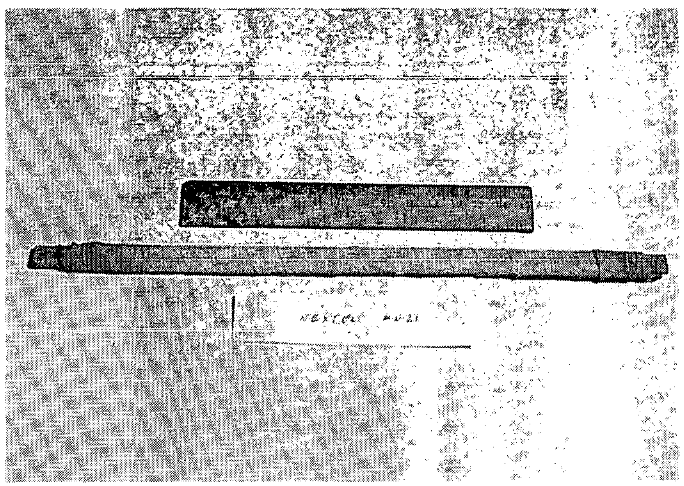
Fig. B5. (Contd.)



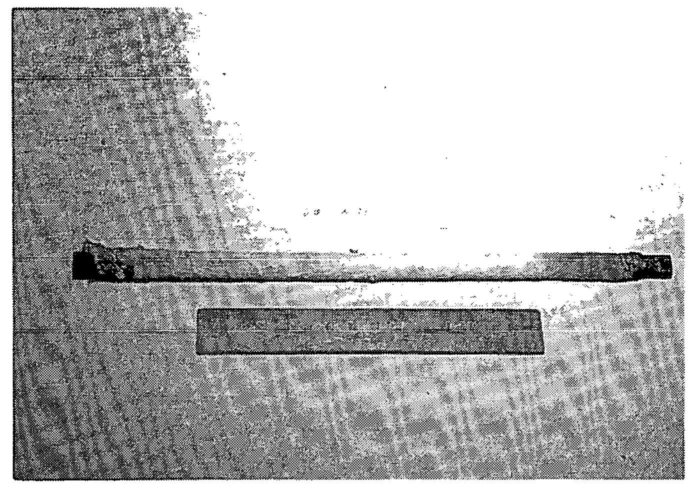
m. Sample N20 Before (ANL Neg. No. 15539K, Frame 7A)



n. Sample N20 After (ANL Neg. No. 16375K, Frame 10A)

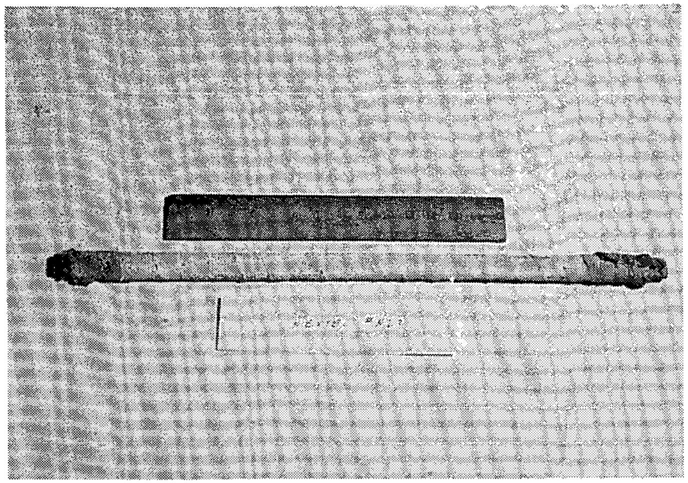


o. Sample N21 Before (ANL Neg. No. 15539K, Frame 8A)

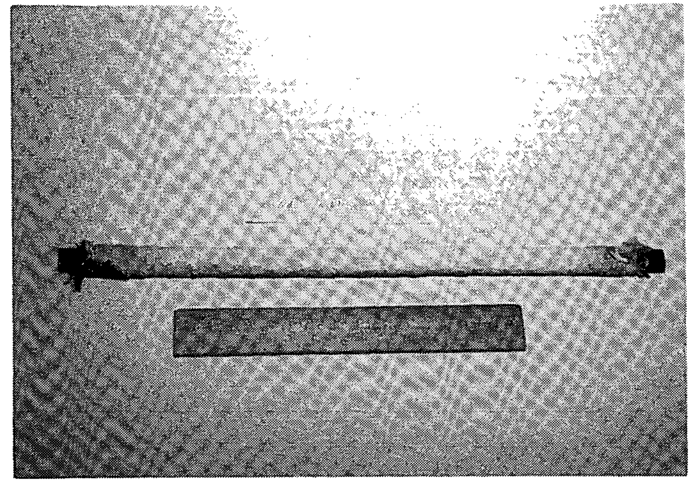


p. Sample N21 After (ANL Neg. No. 16375K, Frame 11A)

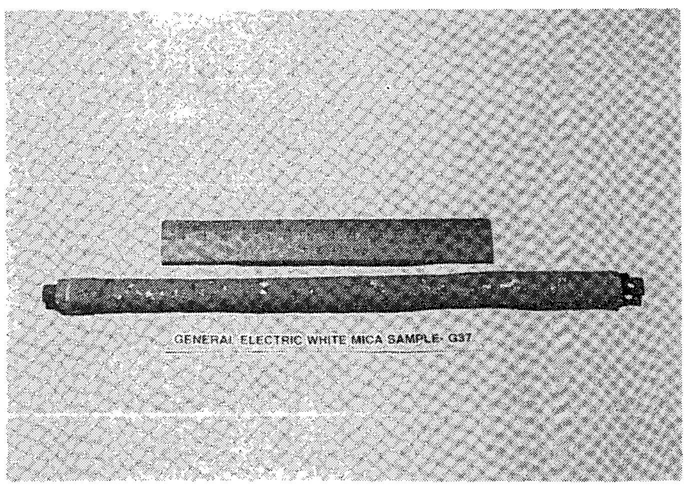
Fig. B5. (Contd.)



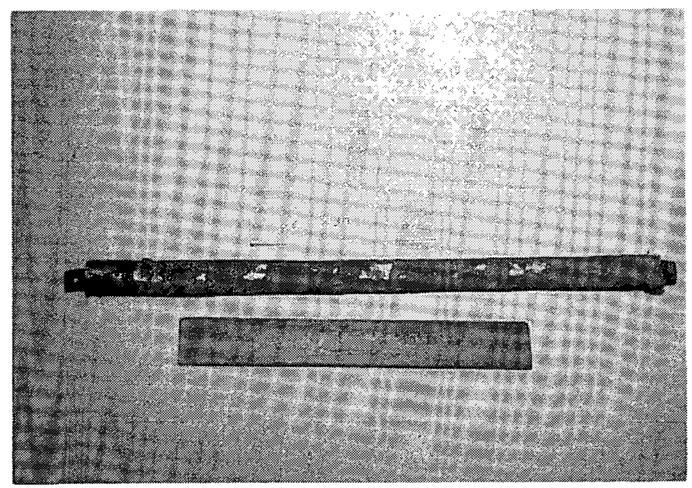
q. Sample N22 Before (ANL Neg. No. 15539K, Frame 9A)



r. Sample N22 After (ANL Neg. No. 16375K, Frame 12A)

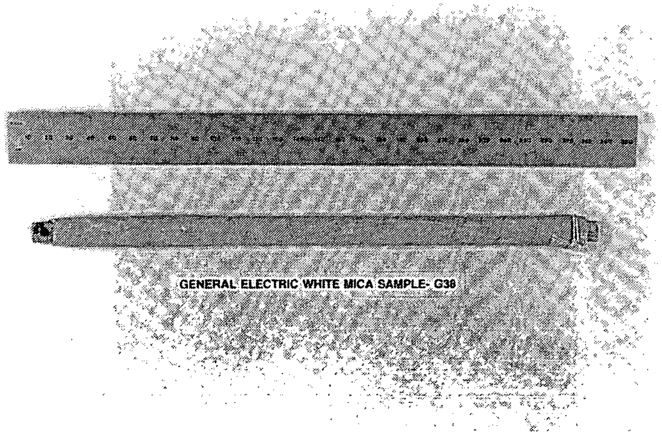


s. Sample G37 Before (ANL Neg. No. 15263K, Frame 22A)

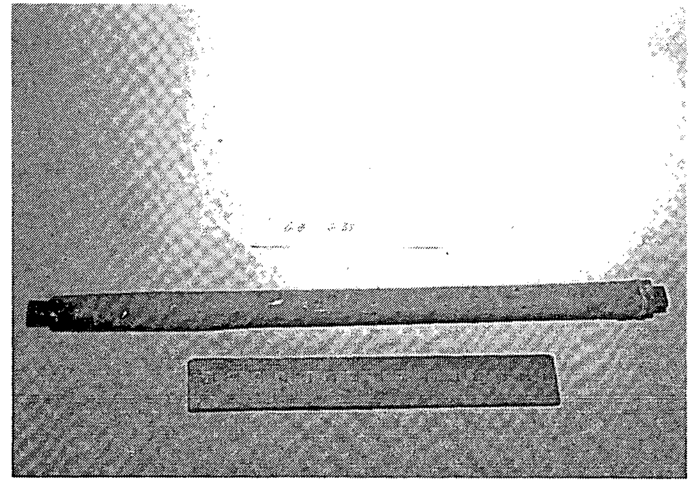


t. Sample G37 After (ANL Neg. No. 16375K, Frame 13A)

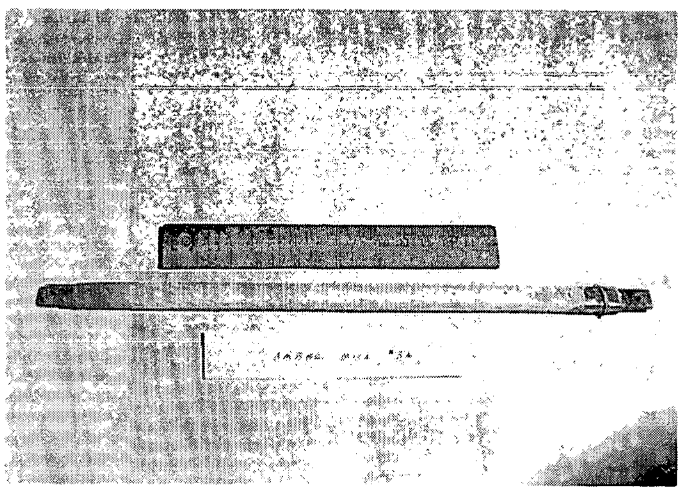
Fig. B5. (Contd.)



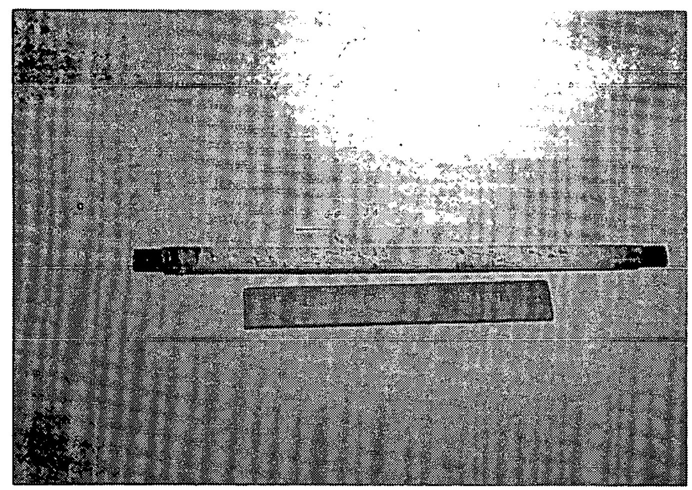
u. Sample G38 Before (ANL Neg. No. 15047, Frame 13)



v. Sample G38 After (ANL Neg. No. 16375K, Frame 16A)

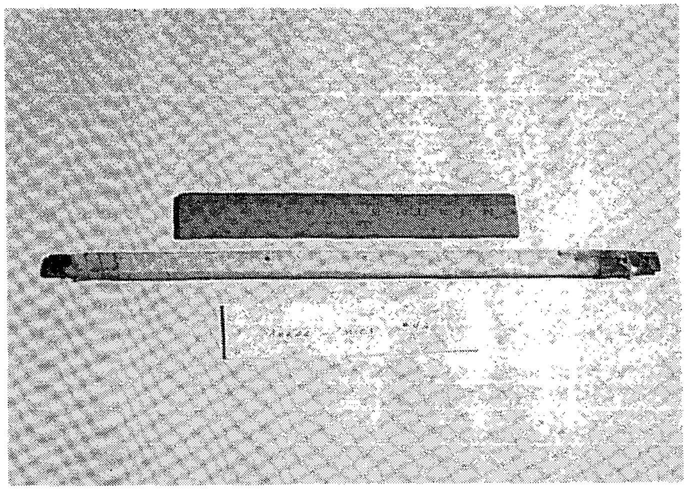


w. Sample 3A-92 Before (ANL Neg. No. 15539K, Frame 5A)

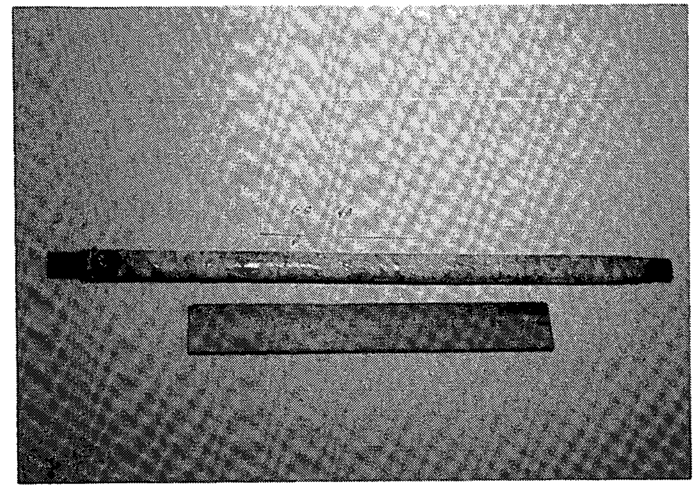


x. Sample 3A-92 After (ANL Neg. No. 16375K, Frame 5A)

Fig. B5. (Contd.)



y. Sample 4A Before (ANL Neg. No. 15539K, Frame 6A)



z. Sample 4A After (ANL Neg. No. 16375K, Frame 6)

Fig. B5. (Contd.)

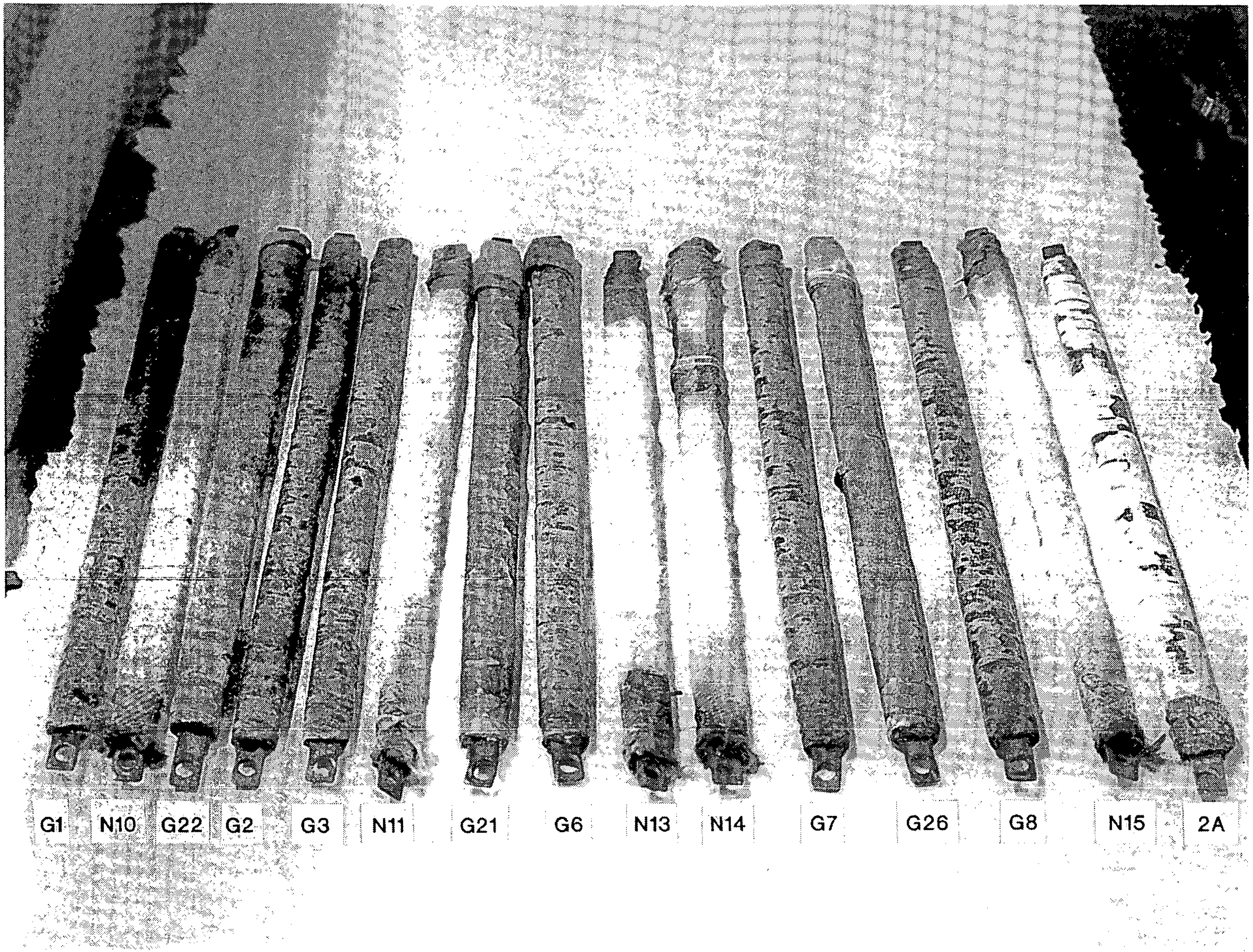


Fig. B6. Bar Samples Before and After Temperature Test